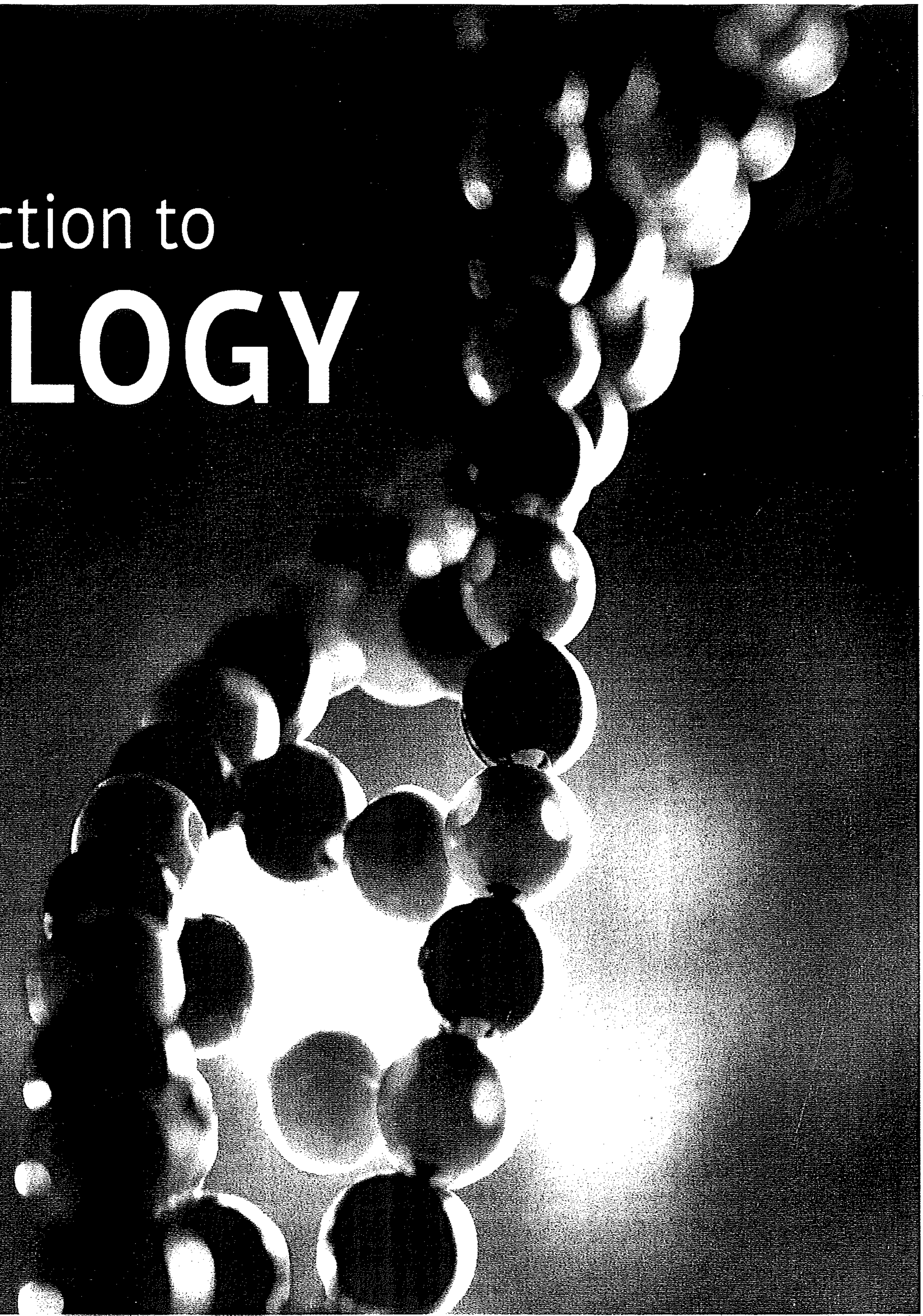
Introduction to
BIOLOGY

BIOL 101



Compiled by
Medhat M. Elbadry, Ph.D.
Wael S. El-Sayed, Ph.D.
Abdellah H. Akhkha, Ph.D.
Tahar Y. Boutraa, Ph.D.
Rafat M.Afifi, Ph.D.

Taibah University,
Preparatory Year Program

ALWAYS LEARNING

PEARSON

INTRODUCTION TO BIOLOGY

PEARSON

We work with leading authors to develop the strongest learning experiences, bringing cutting-edge thinking and best learning practice to a global market. We craft our print and digital resources to do more to help learners not only understand their content, but to see it in action and apply what they learn, whether studying or at work.

Pearson is the world's leading learning company. Our portfolio includes Penguin, Dorling Kindersley, the Financial Times and our educational business, Pearson International. We are also a leading provider of electronic learning programmes and of test development, processing and scoring services to educational institutions, corporations and professional bodies around the world.

Pearson Custom Publishing enables our customers to access a wide and expanding range of market-leading content from world-renowned authors and develop their own tailor-made book. You choose the content that meets your needs and Pearson Custom Publishing produces a high-quality printed book.

Every day our work helps learning flourish, and wherever learning flourishes, so do people.

To learn more please visit us at: www.pearsoncustom.co.uk

INTRODUCTION TO BIOLOGY

BIOL 101

COMPILED BY

Medhat M. Elbadry, Ph.D.
Wael S. El-Sayed, Ph.D.
Abdellah H. Akhkha, Ph.D.
Tahar Y. Boutraa, Ph.D.
Rafat M. Afifi, Ph.D.

TAIBAH UNIVERSITY

PEARSON

Harlow, England • London • New York • Boston • San Francisco • Toronto • Sydney • Auckland • Singapore • Hong Kong
Tokyo • Seoul • Taipei • New Delhi • Cape Town • São Paulo • Mexico City • Madrid • Amsterdam • Munich • Paris • Milan

Pearson Education Limited
Edinburgh Gate
Harlow
Essex CM20 2JE

And associated companies throughout the world

Visit us on the World Wide Web at:
www.pearson.com/uk

Compiled from:
Campbell Biology: Concepts and Connections
Seventh Edition, International Edition
Jane B. Reece, Martha R. Taylor, Eric J. Simon and Jean L. Dickey
ISBN 978 0 321 76158 3

ISBN 978-1-78365-466-6

Printed and bound by The Printers Ltd

Contents

Preface

Quoting the *Campbell Biology: Concepts & Connections* textbook for Taibah University preparatory year students has been the most enjoyable task for our academic pursuits. It was assumed that the book would easily facilitate our students' learning as it had a greater focus on biological concepts and skills.

Consequently, it would help our students to gradually increase their knowledge in the discipline.

However, this version may create some difficulties for our students, in particular, from a terminological aspect. This problem was overcome as both Arabic and English definitions are cited.

The addition of Arabic terminology is twofold; it aids student comprehension and simplifies its usage. This has helped us to successfully overcome learning barriers, making task completion more achievable.

Taibah University's version of the book has simplified the abundance of information that was found in the original version, by editing chapters, modules, sections and paragraphs. It is hoped that this will enhance students' understanding by presenting basic ideas of biology rather than complicated wealth of information.

In order to facilitate this process, we decided that only four units (16 chapters) would be taught as this help students focus on and actualize basic ideas. To comply with the student requirements for the current phase, the Evolution, Diversity and Ecology sections were dispensed with for future opportunities. Furthermore, the units and chapters were carefully selected in order to assure that different fields complied with the requirements of both the Medical and Applied Science students.

Finally, the *Campbell Biology: Concepts & Connections* textbook was carefully chosen for its flexibility, emphasis on knowledge, skills and attitudes and its capacity to serve miscellaneous courses. The modules do not have to be assigned in any particular order and as a result do not impact on student learning. This in turn allows the syllabus to be adapted to our students' need.

We would like to wholeheartedly thank the Deanery of Academic Services for its constructive supervision and support in the preparation of this biology textbook version.

Team Members. Faculty of Science: Biology Department.

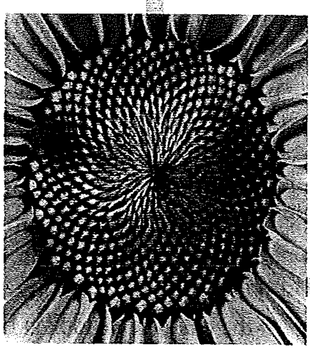
Biology: Exploring Life
Unit 1 and 2: The Life of the Cell, and Cellular Reproduction and Genetics
Wael S. El-Sayed and Abdellah M. Akhkha, Ph.D.
Unit 3: Animals: Form and Function
Rafat M. Afifi, Ph.D.
Unit 4: Plants: Form and Function
Tahar Y. Boutraa, Ph.D.

Team Coordinator
Medhat M. Elbadry, Ph.D.

CHAPTER

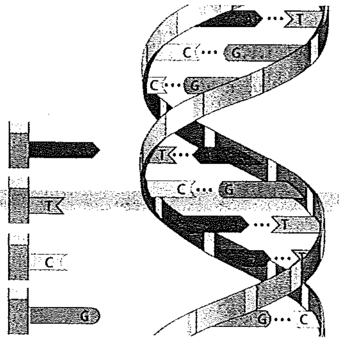
1 Biology: *Exploring Life*

BIG IDEAS



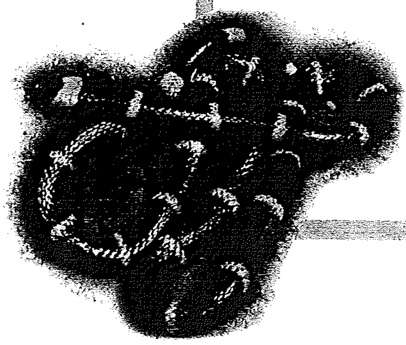
Themes in the Study of Biology
(1.1–1.4)

Common themes help to organize the study of life.



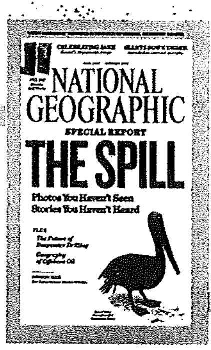
Unity of Life, the Core Theme of Biology
(1.5–1.6)

Unity of life is based on DNA and common genetic code.



The Process of Science
(1.7–1.8)

In studying nature, scientists make observations, form hypotheses, and test predictions with experiments.



Biology and Everyday Life
(1.9)

Learning about biology helps us understand many issues involving science, technology, and society.

Themes in the Study of Biology

1.1 All forms of life share common properties

Defining **biology** as the scientific study of life raises the obvious question: What is *life*? How would you describe what distinguishes living things from nonliving things? Even a small child realizes that a bug or a flower is alive, while a rock or water is not. They, like all of us, recognize life mainly by what living things do. **Figure 1.1** highlights seven of the properties and processes that we associate with life.

(1) *Order*. This close-up of a sunflower illustrates the highly ordered structure that typifies life. Living cells are the basis of this complex organization.

(2) *Reproduction*. Organisms reproduce their own kind. Here an emperor penguin protects its baby.

(3) *Growth and development*. Inherited information in the form of DNA controls the pattern of growth and development of all organisms, including this hatching crocodile.

(4) *Energy processing*. When this bear eats its catch, it will use the chemical energy stored in the fish to power its own activities and chemical reactions.

(5) *Response to the environment*. All organisms respond to environmental stimuli. This Venus flytrap closed its trap rapidly in response to the stimulus of a damselfly landing on it.

(6) *Regulation*. Many types of mechanisms regulate an organism's internal environment, keeping it within limits that sustain life. Pictured here is a typical lemur behavior with a regulatory function—"sunbathing"—which helps raise the animal's body temperature on cold mornings.

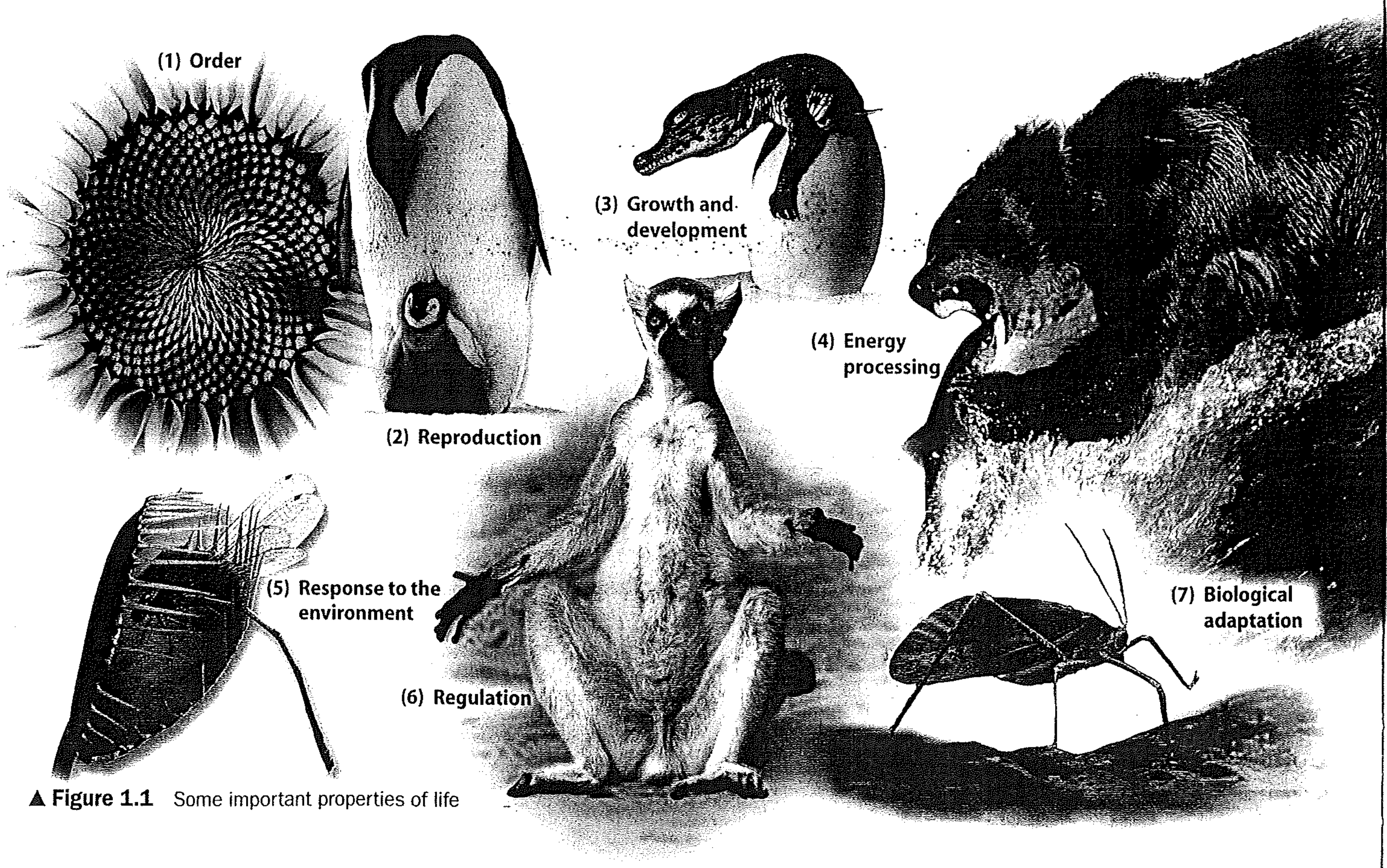
(7) *Biological adaptation*. The leaflike appearance of this katydid camouflages it in its environment. Such adaptations appear over many generations as individuals with traits best suited to their environment have greater reproductive success and pass their traits to offspring.

Figure 1.1 reminds us that the living world is wondrously varied. How do biologists make sense of this diversity and complexity, and how can you? Indeed, biology is a subject of enormous scope that gets bigger every year. One of the ways to help you organize all this information is to connect what you learn to a set of themes that you will encounter throughout your study of life. The next few modules introduce several of these themes: novel properties emerging at each level of biological organization, the cell as the fundamental unit of life, the correlation of structure and function, and the exchange of matter and energy as organisms interact with the environment. We then focus on the core theme of biology—adaption, the theme that makes sense of both the unity and diversity of life. And in the final two sections of the chapter, we look at the process of science and the relationship of biology to our everyday lives.

Let's begin our journey with a tour through the levels of the biological hierarchy.

? How would you define life?

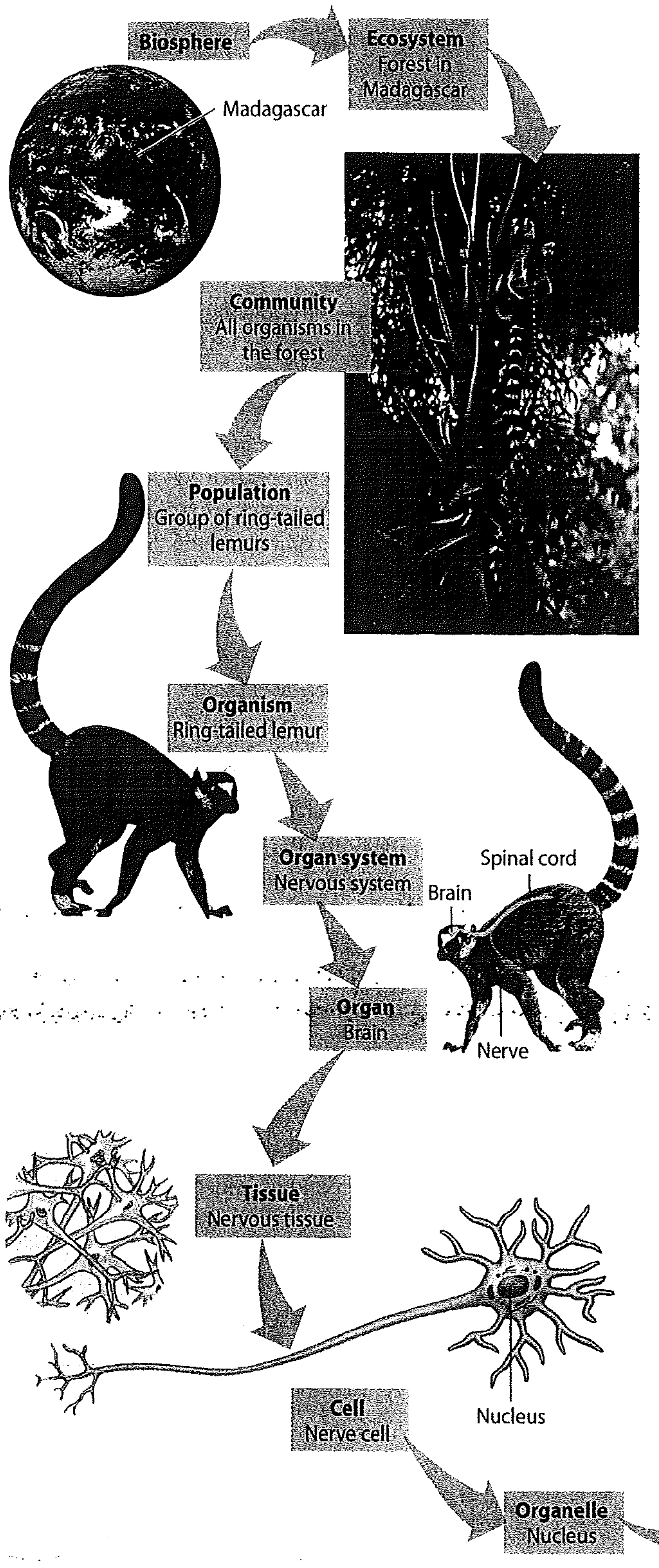
Life can be defined by a set of common properties such as those described in this module.

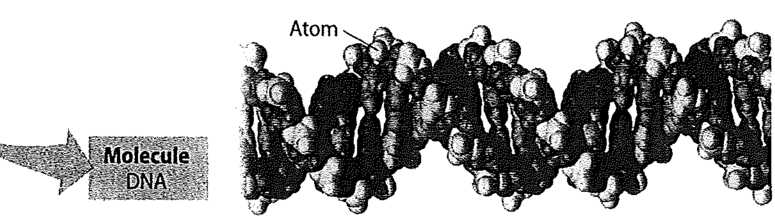


▲ **Figure 1.1** Some important properties of life

1.2 In life's hierarchy of organization, new properties emerge at each level

As **Figure 1.2** illustrates, the study of life extends from the global scale of the biosphere to the microscopic scale of molecules. At the upper left we take a distant view of the **biosphere**, all of the environments on Earth that support life. These include most regions of land, bodies of water, and the lower atmosphere.





▲ **Figure 1.2** Life's hierarchy of organization

A closer look at one of these environments brings us to the level of an **ecosystem**, which consists of all the organisms living in a particular area, as well as the physical components with which the organisms interact, such as air, soil, water, and sunlight.

The entire array of organisms in an ecosystem is called a **community**. The community in this forest ecosystem in Madagascar includes the lemurs and the agave plant they are eating, as well as birds, snakes, and catlike carnivores called civets; a huge diversity of insects; many kinds of trees and other plants; fungi; and enormous numbers of microscopic protists and bacteria. Each unique form of life is called a species.

A **population** includes all the individuals of a particular species living in an area, such as all the ring-tailed lemurs in the forest community. Next in the hierarchy is the **organism**, an individual living thing.

Within a complex organism such as a lemur, life's hierarchy continues to unfold. An **organ system**, such as the circulatory system or nervous system, consists of several organs that cooperate in a specific function. For instance, the organs of the nervous system are the brain, the spinal cord, and the nerves. A lemur's nervous system controls its actions, such as climbing trees.

An **organ** is made up of several different **tissues**, each made up of a group of similar cells that perform a specific function. A **cell** is the fundamental unit of life. In the nerve cell shown here, you can see several organelles, such as the nucleus. An **organelle** is a membrane-enclosed structure that performs a specific function in a cell.

Finally, we reach the level of molecules in the hierarchy. A **molecule** is a cluster of small chemical units called atoms held together by chemical bonds. Our example in Figure 1.2 is a computer graphic of a section of DNA (deoxyribonucleic acid)—the molecule of inheritance.

Now let's work our way in the opposite direction in Figure 1.2, moving up life's hierarchy from molecules to the biosphere. It takes many molecules to build organelles, numerous organelles to make a cell, many cells to make a tissue, and so on. At each new level, there are novel properties that arise, properties that were not present at the preceding level. For example, life emerges at the level of the cell—a test tube full of organelles is not alive. Such **emergent properties** represent an important theme of biology. The familiar saying that "the whole is greater than the sum of its parts" captures this idea. The emergent properties of each level result from the specific arrangement and interactions of its parts.

? **Which of these levels of biological organization includes all others in the list: cell, molecule, organ, tissue?**

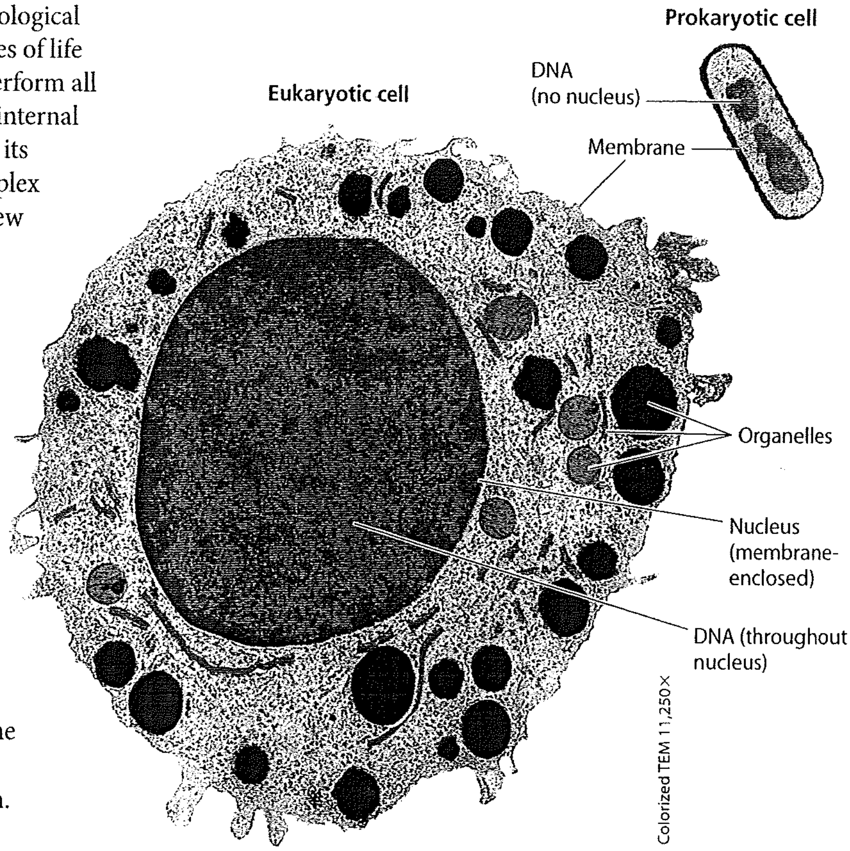
Organ.

1.3 Cells are the structural and functional units of life

The cell has a special place in the hierarchy of biological organization. It is the level at which the properties of life emerge—the lowest level of structure that can perform all activities required for life. A cell can regulate its internal environment, take in and use energy, respond to its environment, and develop and maintain its complex organization. The ability of cells to give rise to new cells is the basis for all reproduction and for the growth and repair of multicellular organisms.

All organisms are composed of cells. They occur singly as a great variety of unicellular (single-celled) organisms, such as amoebas and most bacteria. And cells are the subunits that make up multicellular organisms, such as lemurs and trees. Your body consists of trillions of cells of many different kinds.

All cells share many characteristics. For example, every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings. And every cell uses DNA as its genetic information. There are two basic types of cells. **Prokaryotic cells** were the first to develop and were Earth's sole inhabitants for about the first 1.5 billion years of life on Earth. Fossil evidence indicates that **eukaryotic cells** developed about 2.1 billion years ago.



▲ **Figure 1.3** Contrasting the size and complexity of prokaryotic and eukaryotic cells (shown here approximately 11,250 times their real size)

Figure 1.3 shows these two types of cells as artificially colored photographs taken with an electron microscope. A prokaryotic cell is much simpler and usually much smaller than a eukaryotic cell. The cells of the microorganisms we call bacteria are prokaryotic. Plants, animals, fungi, and protists are all composed of eukaryotic cells. As you can see in Figure 1.3, a eukaryotic cell is subdivided by membranes into many functional compartments, called organelles. These include a nucleus, which houses the cell's DNA.

The properties of life emerge from the ordered arrangement and interactions of the structures of a cell. Such a combination of components forms a more complex organization that we can call a *system*. Cells are examples of biological systems, as are organisms and ecosystems. Systems and their emergent properties are not unique to life. Consider a box of bicycle parts. When all of the individual parts are properly assembled, the result is a mechanical system you can use for exercise or transportation.

The emergent properties of life, however, are particularly challenging to study because of the unrivaled complexity of biological systems. At the cutting edge of large-scale research today is an approach called **systems biology**. The goal of systems biology is to construct models for the dynamic behavior of whole systems based on studying the interactions among the parts. Biological systems can range from the functioning of the biosphere to the molecular machinery of an organelle.

Cells illustrate another theme of biology: the correlation of structure and function. Experience shows you that form generally fits function. A screwdriver tightens or loosens screws, a hammer pounds nails. Because of their form, these tools can't do each other's jobs. Applied to biology, this theme of form fitting function is a guide to the structure of life at all its organizational levels. For example, the long extension of the nerve cell shown in Figure 1.2 enables it to transmit impulses across long distances in the body. Often, analyzing a biological structure gives us clues about what it does and how it works.

The activities of organisms are all based on cells. For example, your every thought is based on the actions of nerve cells, and your movements depend on muscle cells. Even a global process such as the cycling of carbon is the result of cellular activities, including the photosynthesis of plant cells and the cellular respiration of nearly all cells, a process that uses oxygen to break down sugar for energy and releases carbon dioxide. In the next module, we explore these processes and how they relate to the theme of organisms interacting with their environments.

? Why are cells considered the basic units of life?

They are the lowest level in the hierarchy of biological organization at which the properties of life emerge.

1.4 Organisms interact with their environment, exchanging matter and energy

An organism interacts with its environment, which includes other organisms as well as physical factors. **Figure 1.4** is a simplified diagram of such interactions taking place in a forest ecosystem in Madagascar. Plants are the *producers* that provide the food for a typical ecosystem. A tree, for example, absorbs water (H_2O) and minerals from the soil through its roots, and its leaves take in carbon dioxide (CO_2) from the air. In photosynthesis, a tree's leaves use energy from sunlight to convert CO_2 and H_2O to sugar and oxygen (O_2). The leaves release O_2 to the air, and the roots help form soil by breaking up rocks. Thus, both organism and environment are affected by the interactions between them.

The *consumers* of the ecosystem eat plants and other animals. The lemur in Figure 1.4 eats the leaves and fruits of the tamarind tree. To release the energy in food, animals (as well as plants and most other organisms) take in O_2 from the air and release CO_2. An animal's wastes return other chemicals to the environment.

Another vital part of the ecosystem includes the small animals, fungi, and bacteria in the soil that decompose wastes and the remains of dead organisms. These *decomposers* act as recyclers, changing complex matter into simpler mineral nutrients that plants can absorb and use.

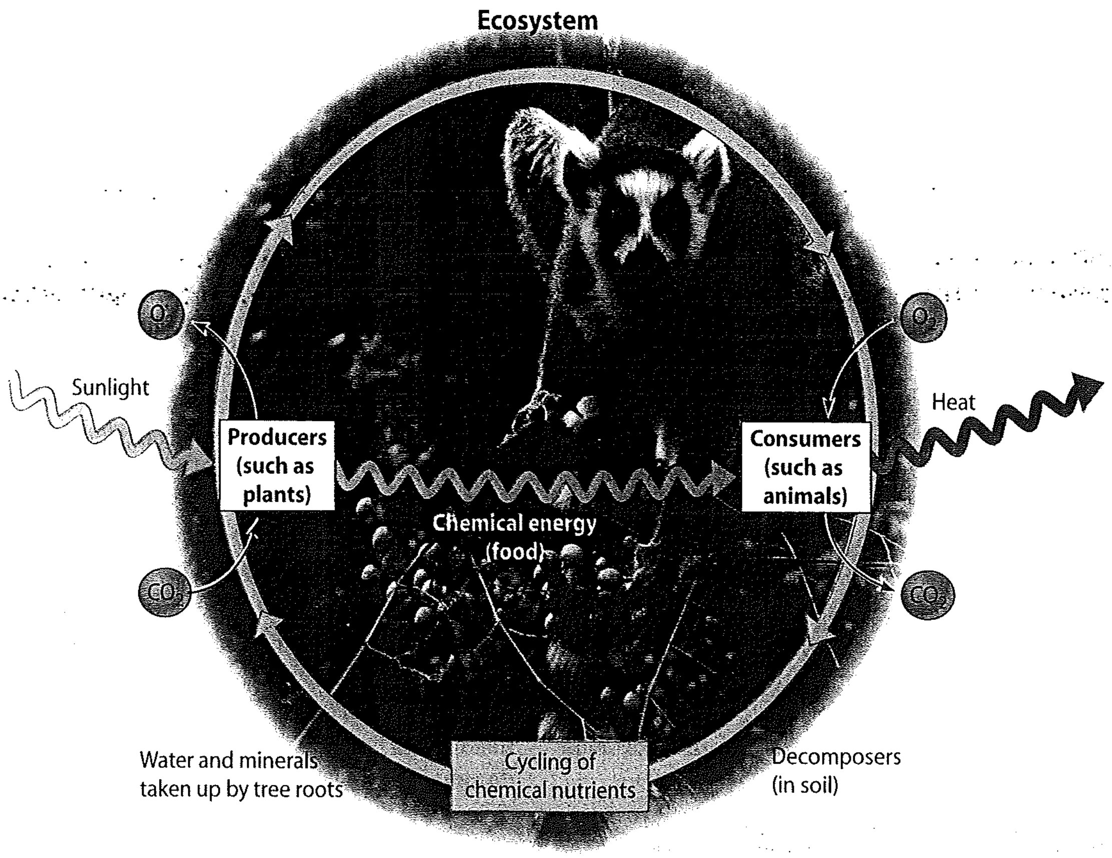
The dynamics of ecosystems include two major processes—the recycling of chemical nutrients and the flow of energy. These processes are illustrated in Figure 1.4. The most basic chemicals necessary for life—carbon dioxide, oxygen, water, and various minerals—cycle within an ecosystem from the air and soil to plants, to animals and decomposers, and back to the air and soil (blue arrows in the figure).

By contrast, an ecosystem gains and loses energy constantly. Energy flows into the ecosystem when plants and other photosynthesizers absorb light energy from the sun (yellow arrow) and convert it to the chemical energy of sugars and other complex molecules. Chemical energy (orange arrow) is then passed through a series of consumers and, eventually, decomposers, powering each organism in turn. In the process of these energy conversions between and within organisms, some energy is converted to heat, which is then lost from the system (red arrow). In contrast to chemical nutrients, which recycle within an ecosystem, energy flows through an ecosystem, entering as light and exiting as heat.

In this first section, we have touched on several themes of biology, from emergent properties in the biological hierarchy of organization, to cells as the structural and functional units of life, to the exchange of matter and energy as organisms interact with their environment. In the next section, we begin our exploration of unity of life, the core theme of biology.

? Explain how the photosynthesis of plants functions in both cycling of chemical nutrients and the flow of energy in an ecosystem.

Photosynthesis uses light energy to convert carbon dioxide and water to energy-rich food, making it the pathway by which both chemical nutrients and energy become available to most organisms.

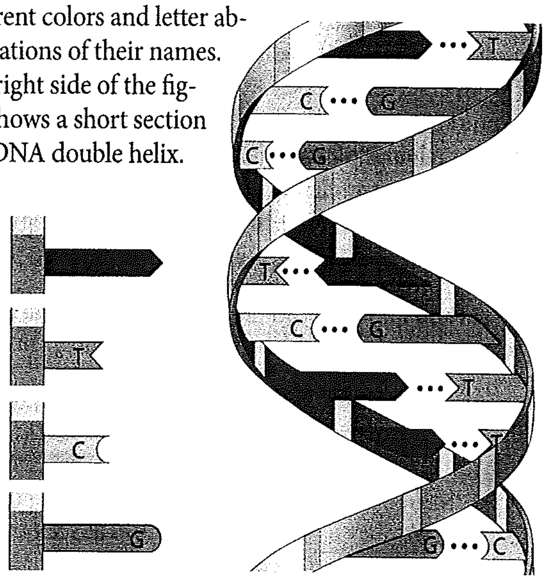


▲ **Figure 1.4** The cycling of nutrients and flow of energy in an ecosystem

Unity of Life, the Core Theme of Biology

1.5 The unity of life is based on DNA and a common genetic code

All cells have DNA, and the continuity of life depends on this universal genetic material. DNA is the chemical substance of **genes**, the units of inheritance that transmit information from parents to offspring. Genes, which are grouped into very long DNA molecules called chromosomes, also control all the activities of a cell. The molecular structure of DNA accounts for these functions. Let us explain: Each DNA molecule is made up of two long chains coiled together into what is called a double helix. The chains are made up of four kinds of chemical building blocks. **Figure 1.5** illustrates these four building blocks, called nucleotides, with different colors and letter abbreviations of their names. The right side of the figure shows a short section of a DNA double helix.



▲ **Figure 1.5** The four building blocks of DNA (left); part of a DNA double helix (right)

The way DNA encodes a cell's information is analogous to the way we arrange letters of the alphabet into precise sequences with specific meanings. The word *rat*, for example, conjures up an image of a rodent; *tar* and *art*, which contain the same letters, mean very different things. We can think of the four building blocks as the alphabet of inheritance. Specific sequential arrangements of these four chemical letters encode precise information in genes, which are typically hundreds or thousands of "letters" long.

The DNA of genes provides the blueprints for making proteins, and proteins serve as the tools that actually build and maintain the cell and carry out its activities. A bacterial gene may direct the cell to "Make a yellow pigment." A particular human gene may mean "Make the hormone insulin." All forms of life use essentially the same genetic code to translate the information stored in DNA into proteins. This makes it possible to engineer cells to produce proteins normally found only in some other organism. Thus, bacteria can be used to produce insulin for the treatment of diabetes by inserting a gene for human insulin into bacterial cells.

The diversity of life arises from differences in DNA sequences—in other words, from variations on the common theme of storing genetic information in DNA. Bacteria and humans are different because they have different genes. But both sets of instructions are written in the same language.

In the next module, we see how biologists attempt to organize the diversity of life.

? What is the chemical basis for all of life's kinship?

DNA as the genetic material.

1.6 The diversity of life can be arranged into three domains

We can think of biology's enormous scope as having two dimensions. The "vertical" dimension, which we examined in Module 1.2, is the size scale that stretches from molecules to the biosphere. But biology also has a "horizontal" dimension, spanning across the great diversity of organisms existing now and over the long history of life on Earth.

Grouping Species Diversity is a hallmark of life. Biologists have so far identified and named about 1.8 million species, and thousands more are identified each year. Estimates of the total number of species range from 10 million to over 100 million. Whatever the actual number, biologists face a major challenge in attempting to make sense of this enormous variety of life.

There seems to be a human tendency to group diverse items according to similarities. We may speak of bears or butterflies, though we recognize that each group includes many different species. We may even sort groups into broader categories, such as mammals and insects. Taxonomy, the branch of biology that names and classifies species, arranges species into a hierarchy of broader and broader groups, from genus, family, order, class, and phylum, to kingdom.

The Three Domains of Life Until the 1990s, most biologists used a taxonomic scheme that divided all of life into five kingdoms. But new methods for assessing phylogenetic relationships, such as comparison of DNA sequences, have led to an ongoing reevaluation of the number and boundaries of kingdoms. As that debate continues, however, there is consensus that life can be organized into three higher levels called **domains**. **Figure 1.6**, on the facing page, shows representatives of the three domains: Bacteria, Archaea, and Eukarya.

Domains **Bacteria** and **Archaea** both consist of prokaryotes, organisms with prokaryotic cells. Most prokaryotes are

single-celled and microscopic. The photos of the prokaryotes in Figure 1.6 were made with an electron microscope, and the number along the side indicates the magnification of the image. Bacteria and archaea were once combined in a single kingdom. But much evidence indicates that they represent two very distinct branches of life, each of which includes multiple kingdoms.

Bacteria are the most diverse and widespread prokaryotes. In the photo of bacteria in Figure 1.6, each of the rod-shaped structures is a bacterial cell.

Many of the prokaryotes known as archaea live in Earth's extreme environments, such as salty lakes and boiling hot springs. Each round structure in the photo of archaea in Figure 1.6 is an archaeal cell.

All the eukaryotes, organisms with eukaryotic cells, are grouped in domain **Eukarya**. As you learned in Module 1.3, eukaryotic cells have a nucleus and other internal structures called organelles.

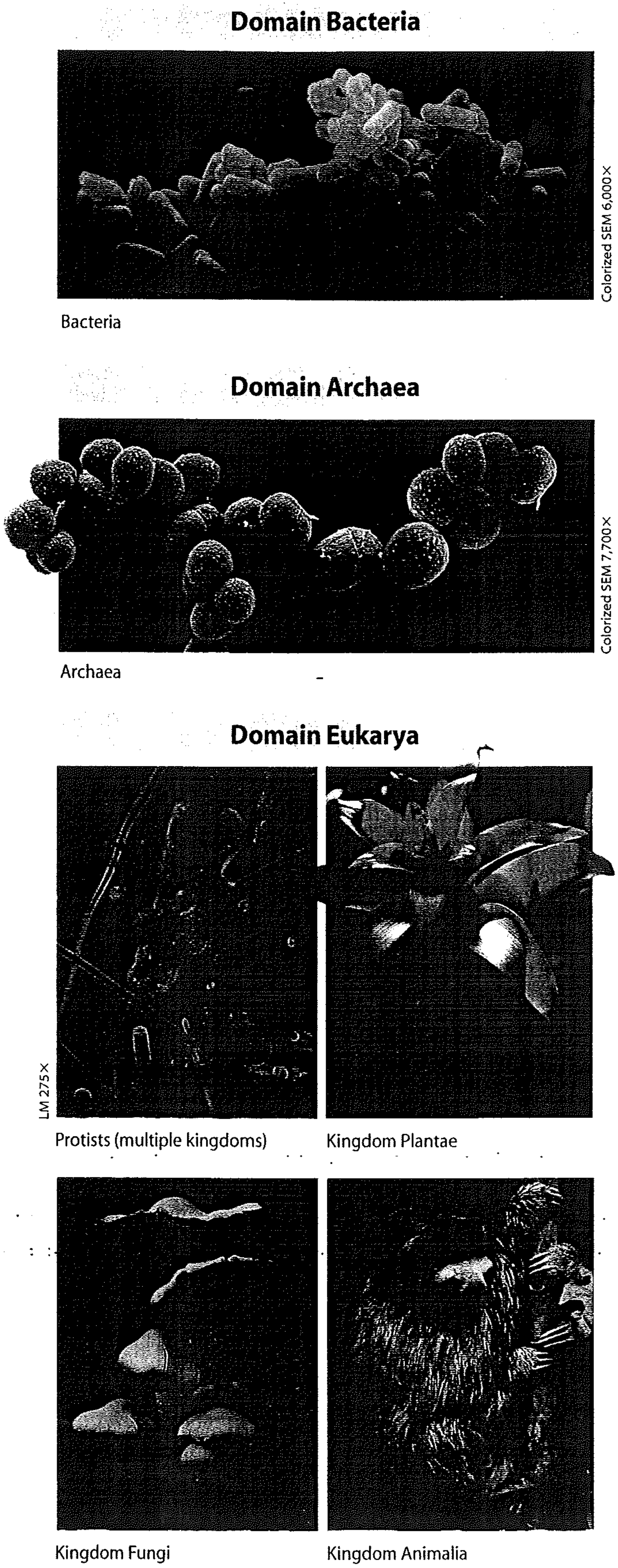
Protists are a diverse collection of mostly single-celled organisms and some relatively simple multicellular relatives. Pictured in Figure 1.6 is an assortment of protists in a drop of pond water. Although protists were once placed in a single kingdom, it is now clear that they do not form a single natural group of species. Biologists are currently debating how to split the protists into groups that accurately reflect their phylogenetic relationships.

The three remaining groups within Eukarya contain multicellular eukaryotes. These kingdoms are distinguished partly by their modes of nutrition. Kingdom Plantae consists of plants, which produce their own food by photosynthesis. The representative of kingdom Plantae in Figure 1.6 is a tropical bromeliad, a plant native to the Americas.

Kingdom Fungi, represented by the mushrooms in Figure 1.6, is a diverse group, whose members mostly decompose the remains of dead organisms and organic wastes and absorb the nutrients into their cells.

Animals obtain food by ingestion, which means they eat other organisms. Representing kingdom Animalia, the sloth in Figure 1.6 resides in the trees of Central and South American rain forests. There are actually members of two other groups in the sloth photo. The sloth is clinging to a tree (kingdom Plantae), and the greenish tinge in the animal's hair is a luxuriant growth of photosynthetic prokaryotes (domain Bacteria). This photograph exemplifies a theme reflected in our book's title: connections between living things. The sloth depends on trees for food and shelter; the tree uses nutrients from the decomposition of the sloth's feces; the prokaryotes gain access to the sunlight necessary for photosynthesis by living on the sloth; and the sloth is camouflaged from predators by its green coat.

The diversity of life and its interconnectedness are evident almost everywhere. Earlier we looked at life's unity in its shared properties, two basic types of cell structure, and common genetic code.



▲ **Figure 1.6** The three domains of life

? **To which of the three domains of life do we belong?**

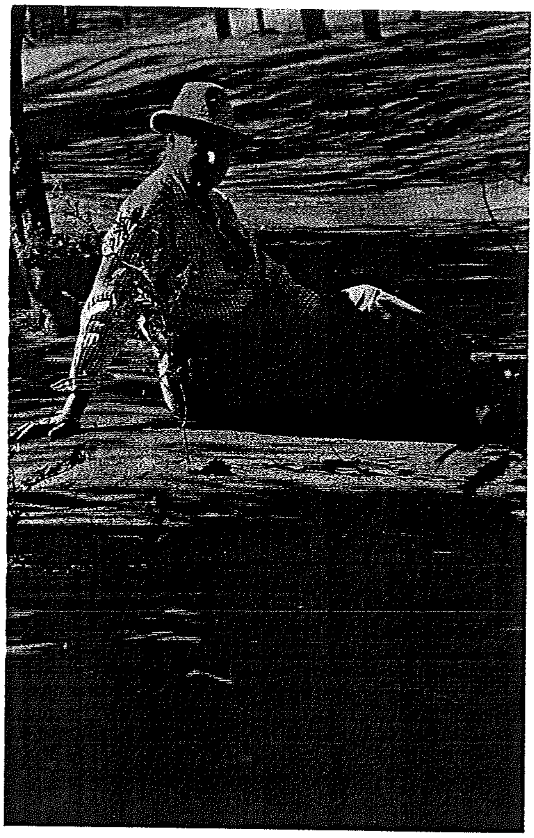
Eukarya.

The Process of Science

1.7 Scientific inquiry is used to ask and answer questions about nature

The word *science* is derived from a Latin verb meaning "to know." Science is a way of knowing—an approach to understanding the natural world. It stems from our curiosity about ourselves and the world around us. And it involves the process of inquiry—a search for information, explanations, and answers to specific questions. Scientific inquiry involves making observations, forming hypotheses, and testing predictions.

Recorded observations and measurements are the data of science. Some data are *quantitative*, such as numerical measurements. Other data may be descriptive, or *qualitative*. For example, primatologist Alison Jolly has spent over 40 years making observations of lemur behavior during field research in Madagascar, amassing data that is mostly qualitative **(Figure 1.7)**.



▲ **Figure 1.7** Alison Jolly with her research subjects, ring-tailed lemurs

Collecting and analyzing observations can lead to conclusions based on a type of logic called **inductive reasoning**. This kind of reasoning derives generalizations from a large number of specific observations. "All organisms are made of cells" is an inductive conclusion based on the discovery of cells in every biological specimen observed over two centuries of time. Careful observations and the inductive conclusions they lead to are fundamental to understanding nature.

Observations often stimulate us to seek natural causes and explanations. Such inquiry usually involves the forming and testing of hypotheses. A **hypothesis** is a proposed explanation for a set of observations. A good hypothesis leads to predictions that scientists can test by recording additional observations or by designing experiments.

Deduction is the type of logic used to come up with ways to test hypotheses. In **deductive reasoning**, the logic flows from general premises to the specific results we should expect if the premises are true. If all organisms are made of cells (premise 1), and humans are organisms (premise 2), then humans are composed of cells (deduction). This deduction is a prediction that can be tested by examining human tissues.

Theories in Science

How is a theory different from a hypothesis? A scientific **theory** is much broader in scope than a hypothesis. It is usually general enough to generate many new, specific hypotheses that can then be tested. And a theory is supported by a large and usually growing body of evidence. Theories that become widely adopted explain a great diversity of observations and are supported by a vast accumulation of evidence.

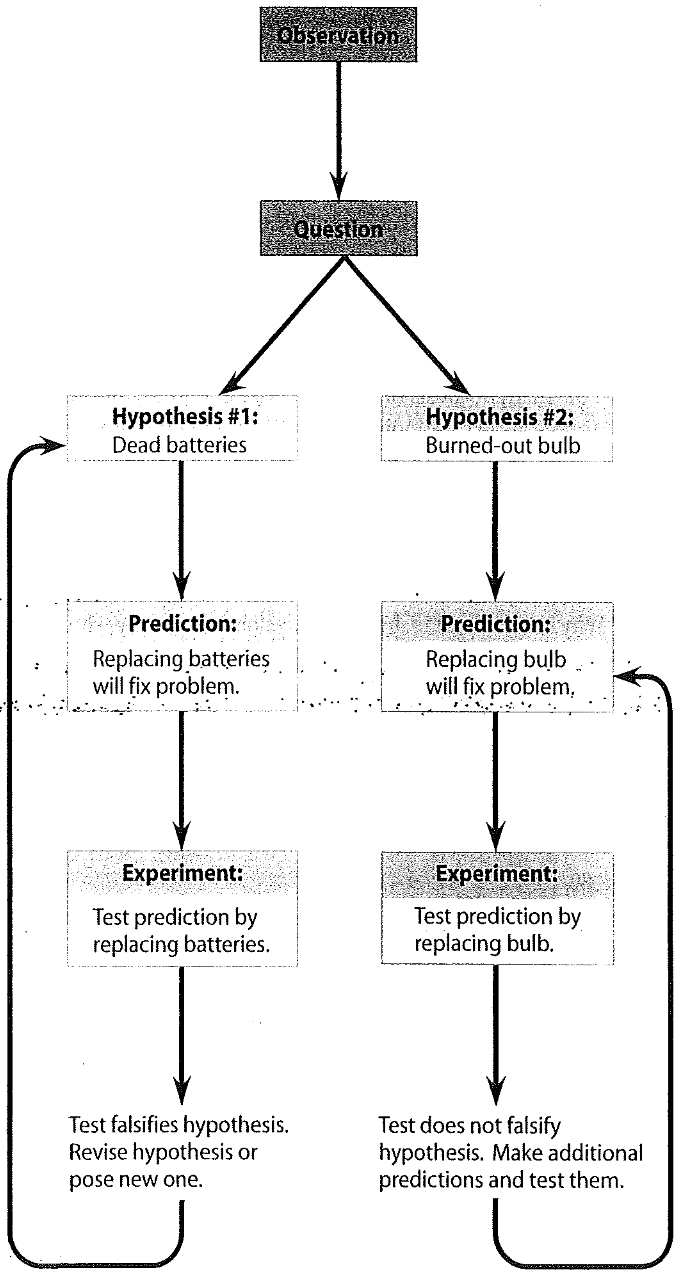
? Contrast inductive reasoning with deductive reasoning.

Inductive reasoning derives a generalization from many observations; deductive reasoning predicts specific outcomes from a general premise.

1.8 Scientists form and test hypotheses and share their results

Let's explore the elements of scientific inquiry with two case studies, one from everyday life and one from a research project.

A Case Study from Everyday Life We all use hypotheses in solving everyday problems. Let's say, for example, that your flashlight fails during a campout. That's an observation. The question is obvious: Why doesn't the flashlight work? Two reasonable hypotheses based on past experience are that either the batteries in the flashlight are dead or the bulb is burned out. Each of these hypotheses leads to predictions you can test with experiments or further observations. For example, the dead-battery hypothesis predicts that replacing the batteries with new ones will fix the problem. **Figure 1.8A** diagrams this campground inquiry.



▲ **Figure 1.8A** An example of hypothesis-based science

The flashlight example illustrates two important points. First, a hypothesis must be *testable*—there must be some way to check its validity. Second, a hypothesis must be *falsifiable*—there must be some observation or experiment that could show that it is not true. As shown on the left in Figure 1.8A, the hypothesis that dead batteries are the sole cause of the problem was falsified by replacing the batteries with new ones. As shown on the right, the burned-out-bulb hypothesis is the more likely explanation. Notice that testing supports a hypothesis not by proving that it is correct but by not eliminating it through falsification. Perhaps the bulb was simply loose and the new bulb was inserted correctly. Testing cannot *prove* a hypothesis beyond a shadow of doubt, because it is impossible to exhaust all alternative hypotheses. A hypothesis gains credibility by surviving multiple attempts to falsify it, while alternative hypotheses are eliminated by testing.

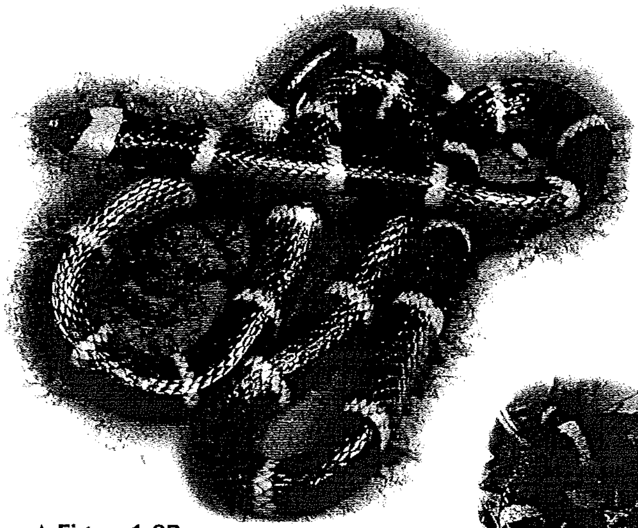
A Case Study from Science To learn more about how science works, let's examine some actual scientific research.

The story begins with a set of observations and generalizations. Many poisonous animals are brightly colored, often with distinctive patterns. This so-called warning coloration apparently says "dangerous species" to potential predators. But there are also mimics. These imposters resemble poisonous species but are actually harmless. A question that follows from these observations is: What is the function of mimicry? A reasonable hypothesis is that mimicry is a biological adaptation that reduces the harmless animal's risk of being eaten.

In 2001, biologists David and Karin Pfennig, along with William Harcombe, one of their undergraduate students, designed an elegant set of field experiments to test the hypothesis that mimics benefit because predators confuse them with the harmful species. A venomous snake called the eastern coral snake has warning coloration: bold, alternating rings of red, yellow, and black (**Figure 1.8B**, on the next page). (A *venomous* species delivers its poison by stinging, stabbing, or biting.) Predators rarely attack these snakes. The predators do not learn this avoidance behavior by trial and error; a first encounter with a coral snake would usually be deadly. Natural selection has apparently increased the frequency of predators that inherit an instinctive avoidance of the coral snake's coloration.

The nonvenomous scarlet king snake mimics the ringed coloration of the coral snake (**Figure 1.8C**). Both types of snakes live in North and South Carolina, but king snakes are also found in regions that have no coral snakes.

The geographic distribution of these snakes made it possible for the researchers to test a key prediction of the mimicry hypothesis: Mimicry should help protect king snakes from predators, but only in regions where coral snakes also live. Avoiding snakes with warning coloration is an adaptation of predator populations that developed in areas where coral snakes are present. Therefore, predators adapted to the warning coloration of coral snakes will attack king snakes less frequently than will predators in areas where coral snakes are absent.



▲ **Figure 1.8B** Eastern coral snake (venomous)

▲ **Figure 1.8C** Scarlet king snake (nonvenomous)

To test this prediction, Harcombe made hundreds of artificial snakes out of wire covered with a claylike substance called plasticine. He made two versions of fake snakes: an *experimental group* with the color pattern of king snakes and a *control group* of plain brown snakes as a basis of comparison.

The researchers placed equal numbers of the two types of artificial snakes in field sites throughout North and South Carolina, including the region where coral snakes are absent. After four weeks, they retrieved the snakes and recorded how many had been attacked by looking for bite or claw marks. The most common predators were foxes, coyotes, and raccoons, but black bears also attacked some of the snakes (**Figure 1.8D**).

The data fit the key prediction of the mimicry hypothesis. The artificial king snakes were attacked less frequently than the artificial brown snakes only in field sites within the geographic range of the venomous coral snakes. The bar graph in **Figure 1.8E** summarizes the results.

This case study is an example of a **controlled experiment**, one that is designed to compare an experimental group (the artificial king snakes, in this case) with a control group (the artificial brown snakes). Ideally, the experimental and control groups differ only in the one factor the experiment is designed to test—in our example, the effect of the snakes' coloration on the behavior of predators. Without the control group, the researchers would not have been able to rule out other variables, such as the number of predators in the different test areas. The experimental design left coloration as the only factor that could account for the low predation rate on the artificial king snakes placed within the range of coral snakes.

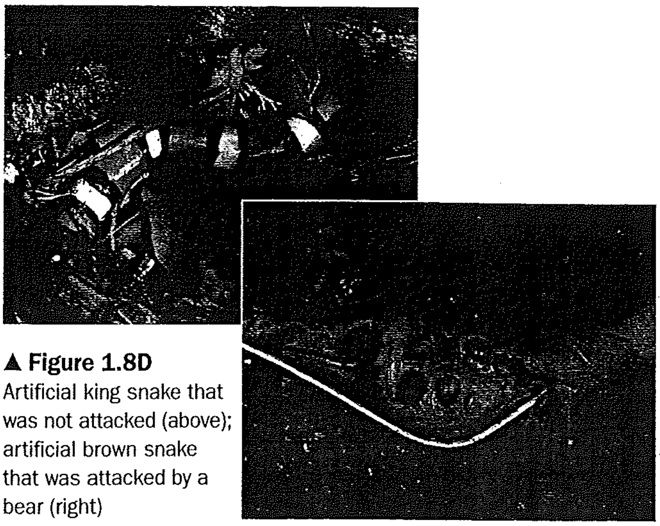
The Culture of Science Science is a social activity, with most scientists working in teams, which often include graduate and undergraduate students. Scientists share information through publications, seminars, meetings, and personal communication. The Internet has added a new medium for this exchange of ideas and data. Scientists build on what has been learned from earlier research and often check each other's claims by attempting to confirm observations or repeat experiments.

Science seeks natural causes for natural phenomena. Thus, the scope of science is limited to the study of structures and processes that we can directly observe and measure. Science can neither support nor falsify hypotheses about supernatural forces or explanations, for such questions are outside the bounds of science.

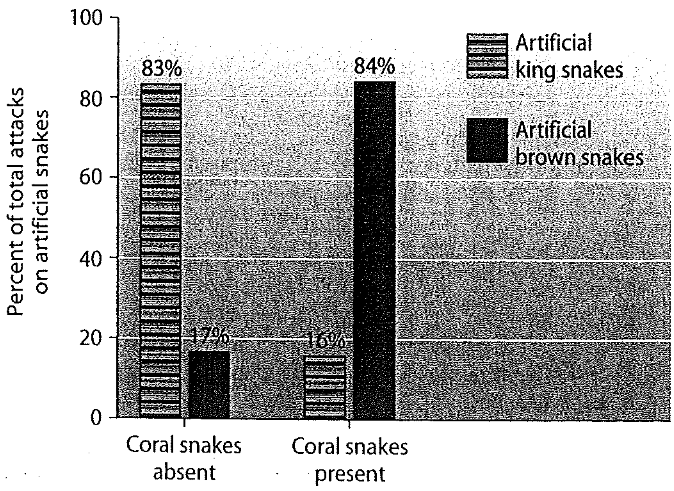
The process of science is necessarily repetitive: In testing a hypothesis, researchers may make observations that call for rejection of the hypothesis or at least revision and further testing. This process allows biologists to circle closer and closer to their best estimation of how nature works. As in all quests, science includes elements of challenge, adventure, and luck, along with careful planning, reasoning, creativity, cooperation, competition, patience, and persistence.

? Why is it difficult to draw a conclusion from an experiment that does not include a control group?

Without a control group, you don't know if the experimental outcome is due to the variable you are trying to test or to some other variable.



▲ **Figure 1.8D** Artificial king snake that was not attacked (above); artificial brown snake that was attacked by a bear (right)



▲ **Figure 1.8E** Results of mimicry experiment

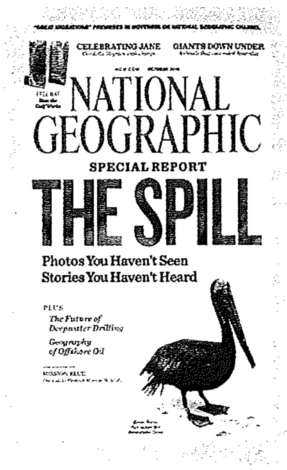
Biology and Everyday Life

CONNECTION 1.9 Biology, technology, and society are connected in important ways

Many issues facing society are related to biology **(Figure 1.9)**. Most of these issues also involve our expanding technology. Science and technology are interdependent, but their basic goals differ. The goal of science is to understand natural phenomena. In contrast, the goal of **technology** is to apply scientific knowledge for some specific purpose. Scientists often speak of "discoveries," while engineers more often speak of "inventions." The beneficiaries of those inventions also include scientists, who use new technology in their research. And scientific discoveries often lead to the development of new technologies.

Technology depends less on the curiosity that drives basic science than on the needs and wants of people and on the social environment of the times. Debates about technology center more on "should we do it" than "can we do it." Should insurance companies have access to individuals' DNA information? Should we permit research with embryonic stem cells?

Technology has improved our standard of living in many ways, but not without adverse consequences. Technology that keeps people healthier has enabled Earth's population to grow 10-fold in the past three centuries and to more than double to 6.8 billion in just the past 40 years. The environmental effects of this growth can be devastating. Global climate change, toxic wastes, deforestation, nuclear accidents, and extinction of species are just some of the repercussions of more and more people wielding more and more technology. Science can help us identify such problems and provide insight into what course of action may prevent further damage. But solutions to these problems have as much to do with politics, economics, and cultural values as with science and technology. Now that science and technology have become such powerful aspects of society, every citizen has a responsibility to develop a reasonable amount of scientific literacy. The crucial science-technology-society relationship is a theme that adds to the significance of any biology course.



▲ **Figure 1.9** Biology and technology in the news

? **How do science and technology interact?**

New scientific discoveries may lead to new technologies; new technologies may increase the ability of scientists to search for new knowledge.

CHAPTER 1 REVIEW

Reviewing the Concepts

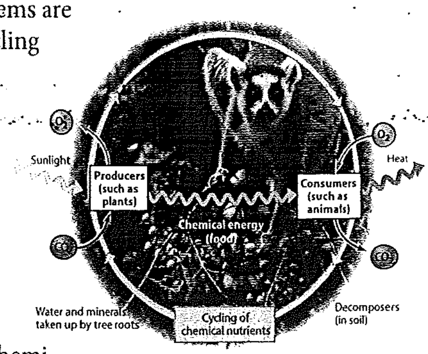
Themes in the Study of Biology (1.1–1.4)

1.1 All forms of life share common properties. Biology is the scientific study of life. Properties of life include order, reproduction, growth and development, energy processing, response to the environment, regulation, and biological adaptation.

1.2 In life's hierarchy of organization, new properties emerge at each level. Biological organization unfolds as follows: biosphere > ecosystem > community > population > organism > organ system > organ > tissue > cell > organelle > molecule. Emergent properties result from the interactions among component parts.

1.3 Cells are the structural and functional units of life. Eukaryotic cells contain membrane-enclosed organelles, including a nucleus containing DNA. Prokaryotic cells are smaller and lack such organelles. Structure is related to function at all levels of biological organization. Systems biology models the complex interactions of biological systems, such as the molecular interactions within a cell.

1.4 Organisms interact with their environment, exchanging matter and energy. Ecosystems are characterized by the cycling of chemical nutrients from the atmosphere and soil through producers, consumers, decomposers, and back to the environment. Energy flows one way through an ecosystem—entering as sunlight, converted to chemical energy by producers, passed on to consumers, and exiting as heat.



Unity of Life, the Core Theme of Biology (1.5–1.6)

1.5 The unity of life is based on DNA and a common genetic code. DNA is responsible for heredity and for programming the activities of a cell. A species' genes are coded in the sequences of the four building blocks making up DNA's double helix.

1.6 The diversity of life can be arranged into three domains. Taxonomy names species and classifies them into a system of broader groups. Domains Bacteria and Archaea consist of prokaryotes. The eukaryotic domain, Eukarya, includes various protists and the kingdoms Fungi, Plantae, and Animalia.

The Process of Science (1.7–1.8)

1.7 Scientific inquiry is used to ask and answer questions about nature. Scientists use inductive reasoning to draw general conclusions from many observations. They form hypotheses and use deductive reasoning to make predictions. Data may be qualitative or quantitative. A scientific theory is broad in scope, generates new hypotheses, and is supported by a large body of evidence.

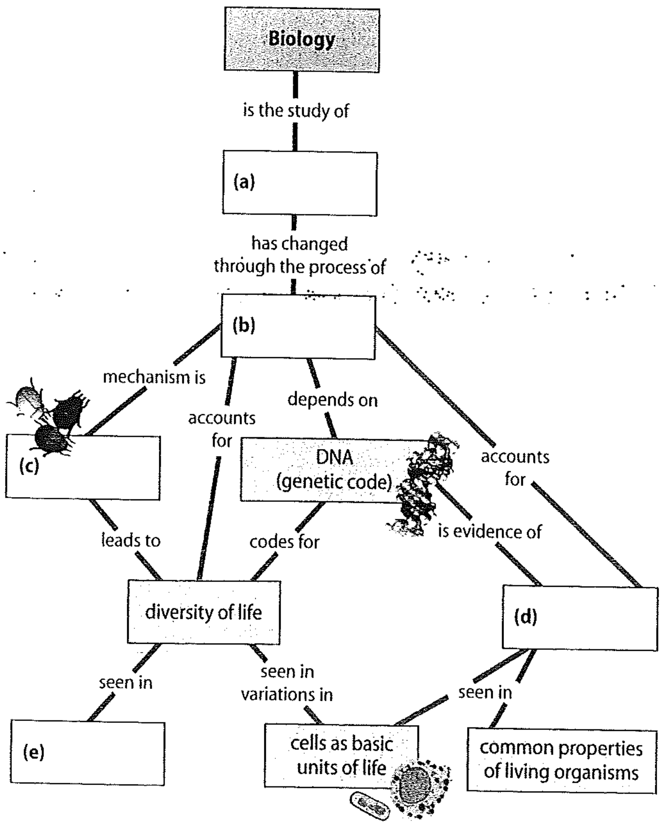
1.8 Scientists form and test hypotheses and share their results. Predictions can be tested with experiments, and results can either falsify or support the hypothesis. In a controlled experiment, the use of control and experimental groups helps to demonstrate the effect of a single variable. Science is a social process; scientists share information and review each other's results.

Biology and Everyday Life (1.9)

1.9 Biology, technology, and society are connected in important ways. Technological advances stem from scientific research, and research benefits from new technologies.

Connecting the Concepts

1. Biology can be described as having both a vertical scale and a horizontal scale. Explain what that means.
2. Complete the following map organizing some of biology's major concepts.



Testing Your Knowledge

Multiple Choice

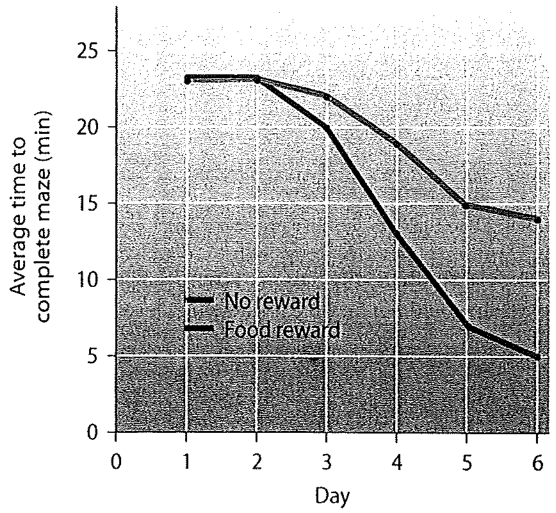
3. Which of the following best describes the logic of the scientific process?
   a. If I generate a testable hypothesis, tests and observations will support it.
   b. If my prediction is correct, it will lead to a testable hypothesis.
   c. If my observations are accurate, they will not falsify my hypothesis.
   d. If my hypothesis is correct, I can make predictions and my results will not falsify my hypothesis.
   e. If my predictions are good and my tests are right, they will prove my hypothesis.
4. Single-celled amoebas and bacteria are grouped into different domains because
   a. amoebas eat bacteria.
   b. bacteria are not made of cells.
   c. bacterial cells lack a membrane-enclosed nucleus.
   d. bacteria decompose amoebas.
   e. amoebas are motile; bacteria are not.
5. A biologist studying interactions among the protists in an ecosystem could *not* be working at which level in life's hierarchy? (*Choose carefully and explain your answer.*)
   a. the population level
   b. the molecular level
   c. the community level
   d. the organism level
   e. the organ level
6. Which of the following questions is outside the realm of science?
   a. Which organisms play the most important role in energy input to a forest?
   b. What percentage of music majors take a biology course?
   c. What is the physical nature of the universe?
   d. What is the influence of the supernatural on current events?
   e. What is the dominance hierarchy in a troop of ring-tailed lemurs?
7. Which of the following statements best distinguishes hypotheses from theories in science?
   a. Theories are hypotheses that have been proved.
   b. Hypotheses are tentative guesses; theories are correct answers to questions about nature.
   c. Hypotheses usually are narrow in scope; theories have broad explanatory power.
   d. Hypotheses and theories are different terms for essentially the same thing in science.
   e. Theories cannot be falsified; hypotheses can be falsified.
8. Which of the following best demonstrates the unity among all living organisms?
   a. descent with modification
   b. common genetic code
   c. emergent properties
   d. natural selection
   e. the three domains
9. The core idea that makes sense of all of biology is
   a. the process of science.
   b. the correlation of function with structure.
   c. systems biology.
   d. unity of life.
   e. the emergence of life at the level of the cell.

Describing, Comparing, and Explaining

10. In an ecosystem, how is the movement of energy similar to that of chemical nutrients, and how is it different?
11. Explain what is meant by this statement: The scientific process is not a rigid method.
12. Contrast technology with science. Give an example of each to illustrate the difference.

Applying the Concepts

13. The graph below shows the results of an experiment in which mice learned to run through a maze.



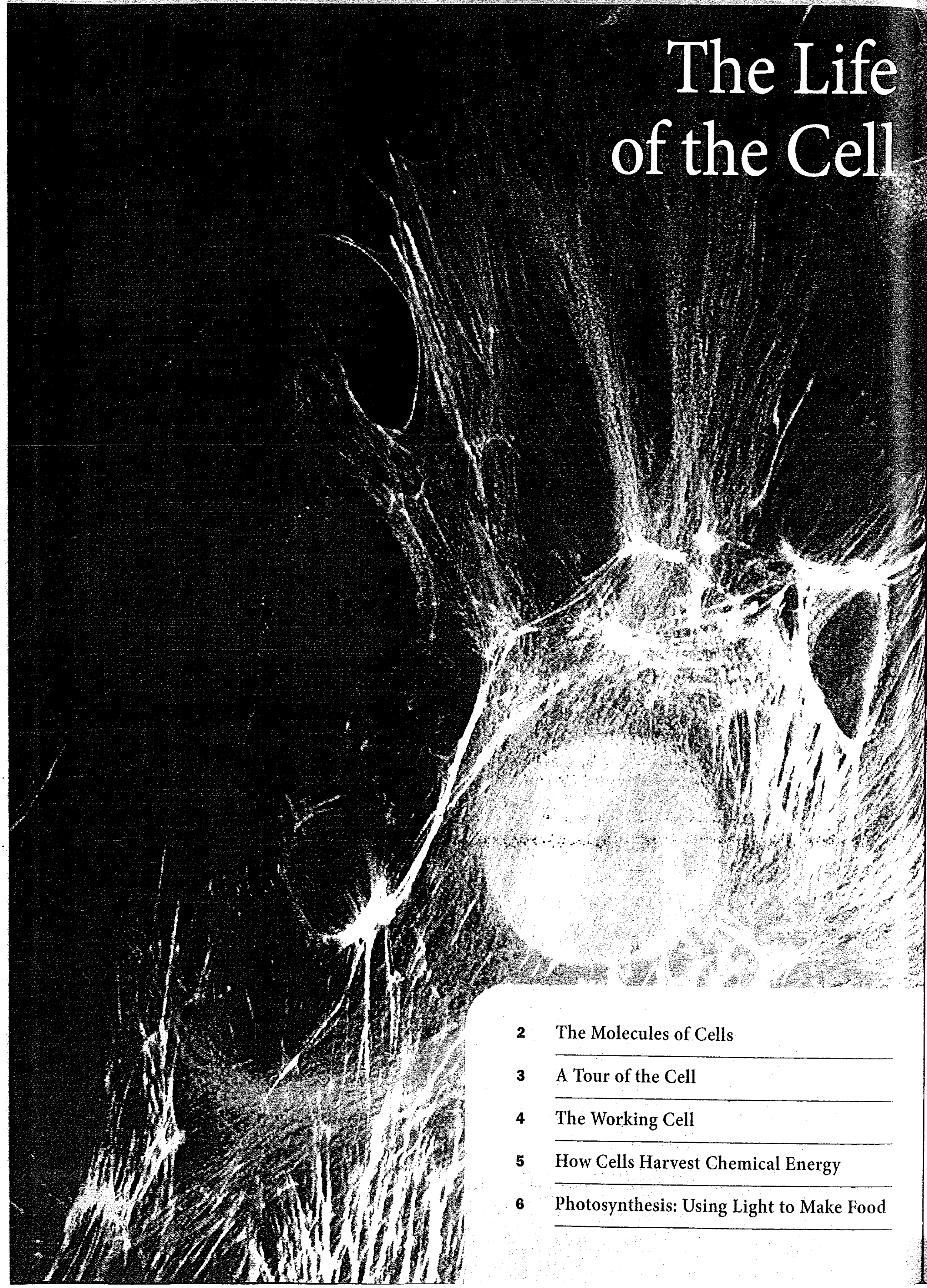
a. State the hypothesis and prediction that you think this experiment tested.
b. Which was the control group and which the experimental? Why was a control group needed?
c. List some variables that must have been controlled so as not to affect the results.
d. Do the data support the hypothesis? Explain.

14. In an experiment similar to the mimicry experiment described in Module 1.8, a researcher counted more predator attacks on artificial king snakes in areas with coral snakes than in areas outside the range of coral snakes. From those numbers, the researcher concluded that the mimicry hypothesis is false. Do you think this conclusion is justified? Why or why not?
15. The fruits of wild species of tomato are tiny compared to the giant beefsteak tomatoes available today. This difference in fruit size is almost entirely due to the larger number of cells in the domesticated fruits. Plant biologists have recently discovered genes that are responsible for controlling cell division in tomatoes. Why would such a discovery be important to producers of other kinds of fruits and vegetables? To the study of human development and disease? To our basic understanding of biology?
16. The news media and popular magazines frequently report stories that are connected to biology. In the next 24 hours, record the ones you hear or read about in three different sources and briefly describe the biological connections in each story.

Answers to all questions can be found in Appendix 1.

UNIT

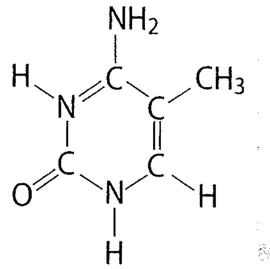
The Life of the Cell



CHAPTER 2

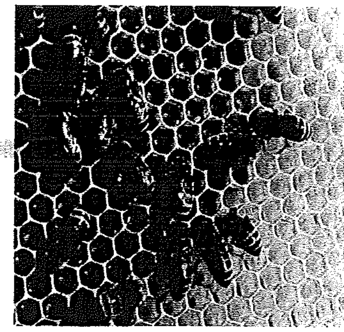
The Molecules of Cells

BIG IDEAS



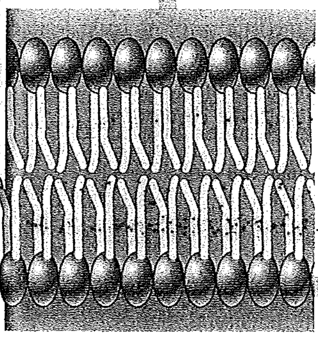
Introduction to Organic Compounds
(2.1–2.3)

Carbon-containing compounds are the chemical building blocks of life.



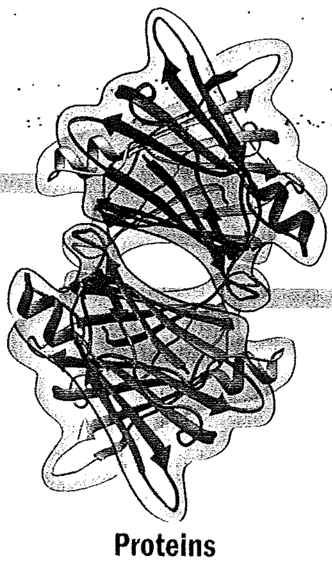
Carbohydrates
(2.4–2.6)

Carbohydrates serve as a cell's fuel and building material.



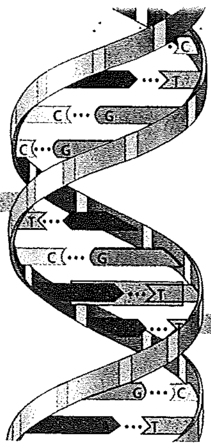
Lipids
(2.7–2.8)

Lipids are hydrophobic molecules with diverse functions.



Proteins
(2.9–2.11)

Proteins are essential to the structures and functions of life.



Nucleic Acids
(2.12–2.13)

Nucleic acids store, transmit, and help express hereditary information.

Introduction to Organic Compounds

2.1 Life's molecular diversity is based on the properties of carbon

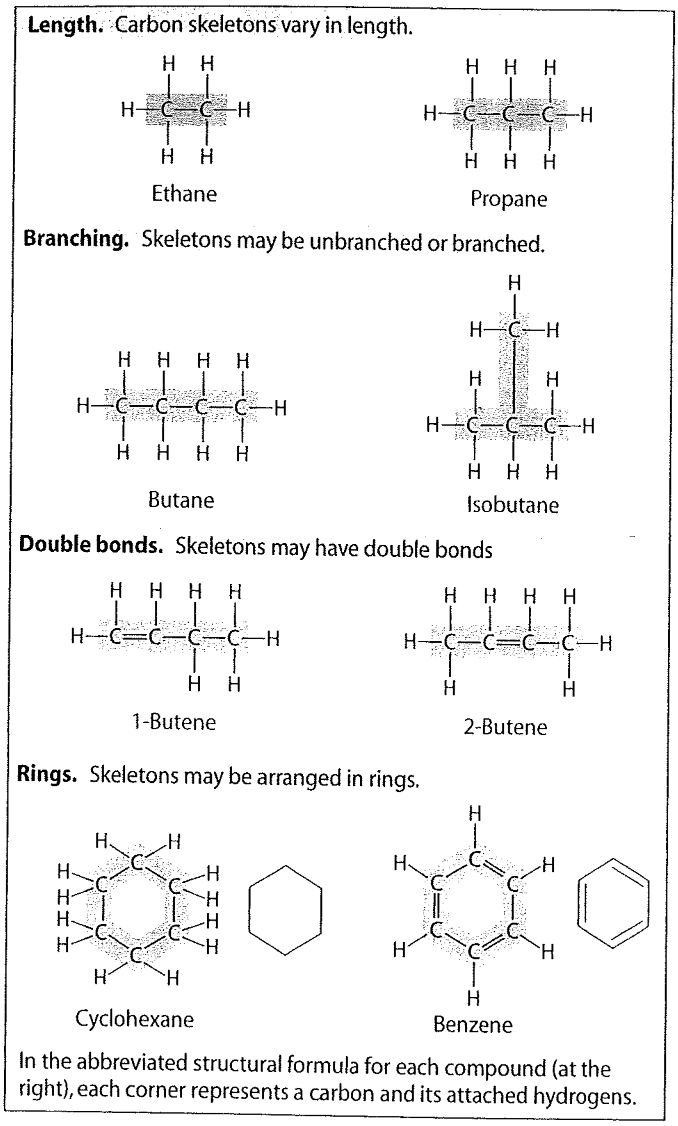
When it comes to making molecules, carbon usually takes center stage. Almost all the molecules a cell makes are composed of carbon atoms bonded to one another and to atoms of other elements. Carbon is unparalleled in its ability to form large and complex molecules, which build the structures and carry out the functions required for life.

Carbon-based molecules are called **organic compounds.** Why are carbon atoms the lead players in the chemistry of life? The number of electrons in the outermost shell of its atoms determines an element's chemical properties. A carbon atom has 4 electrons in a valence shell that holds 8. Carbon completes its outer shell by sharing electrons with other atoms in four covalent bonds. Thus, each carbon atom is a connecting point from which a molecule can branch in up to four directions.

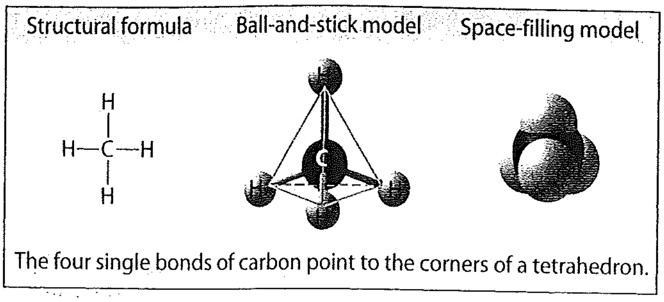
Figure 2.1A illustrates three representations of methane (CH_4), one of the simplest organic molecules. The structural formula shows that covalent bonds link four hydrogen atoms to the carbon atom. Each of the four lines in the formula represents a pair of shared electrons. The two models help you see that methane is three-dimensional, with the space-filling model on the right better portraying its overall shape. The ball-and-stick model shows that carbon's four bonds (the gray "sticks") angle out toward the corners of an imaginary tetrahedron (an object with four triangular sides). The red lines trace this shape, which occurs wherever a carbon atom participates in four single bonds. Different bond angles and shapes occur when carbon atoms form double bonds. Large organic molecules can have very elaborate shapes. And as we will see many times, a molecule's shape often determines its function.

Compounds composed of only carbon and hydrogen are called **hydrocarbons.** Methane and propane are examples of hydrocarbon fuels. As components of fats, longer hydrocarbons provide fuel to your body cells. **Figure 2.1B** illustrates some of the variety of hydrocarbon structures. The chain of carbon atoms in an organic molecule is called a **carbon skeleton** (shaded in gray in the figure). Carbon skeletons can vary in length and can be unbranched or branched. Carbon skeletons may also include double bonds, which can vary in number and location. Some carbon skeletons are arranged in rings.

The two compounds in the second row of Figure 2.1B, butane and isobutane, have the same molecular formula, C_4H_{10}, but differ in the bonding pattern of their carbon skeleton. The two molecules in the third row also have the same numbers of atoms, but they have different three-dimensional shapes because of the location of the double bond. Compounds with the same formula but different structural arrangements are called **isomers.** Isomers can also result from different spatial arrangements of the four partners bonded to a carbon atom. This type of isomer is important in the pharmaceutical industry, because the two isomers of a drug may not be equally effective or may have different (and sometimes harmful) effects. The different shapes of isomers result in unique properties and add greatly to the diversity of organic molecules.



▲ **Figure 2.1B** Four ways that carbon skeletons can vary



▲ **Figure 2.1A** Three representations of methane (CH_4)

? One isomer of methamphetamine is the addictive illegal drug known as "crank." The other is a medicine for sinus congestion. How can you explain the differing effects of the two isomers?

Isomers have different structures, or shapes, and the shape of a molecule usually helps determine the way it functions in the body.

2.2 A few chemical groups are key to the functioning of biological molecules

The unique properties of an organic compound depend not only on the size and shape of its carbon skeleton but also on the groups of atoms that are attached to that skeleton.

Table 2.2 illustrates six chemical groups important in the chemistry of life. The first five are called **functional groups.** They affect a molecule's function by participating in chemical reactions in characteristic ways. These groups are polar, because oxygen or nitrogen atoms exert a strong pull on shared electrons. This polarity tends to make compounds containing these groups **hydrophilic** (water-loving) and therefore soluble in water—a necessary condition for their roles in water-based life. The sixth group, a methyl group, is nonpolar and not reactive, but it affects molecular shape and thus function.

A **hydroxyl group** consists of a hydrogen atom bonded to an oxygen atom, which in turn is bonded to the carbon skeleton. Ethanol, shown in the table, and other organic compounds containing hydroxyl groups are called alcohols.

In a **carbonyl group,** a carbon atom is linked by a double bond to an oxygen atom. If the carbonyl group is at the end of a carbon skeleton, the compound is called an aldehyde; if it is within the chain, the compound is called a ketone. Sugars contain a carbonyl group and several hydroxyl groups.

A **carboxyl group** consists of a carbon double-bonded to an oxygen atom and also bonded to a hydroxyl group. The carboxyl group acts as an acid by contributing an H^+ to a solution and thus becoming ionized. Compounds with carboxyl groups are called carboxylic acids. Acetic acid, shown in the table, gives vinegar its sour taste.

An **amino group** has a nitrogen bonded to two hydrogens and the carbon skeleton. It acts as a base by picking up an H^+ from a solution. Organic compounds with an amino group are called amines. The building blocks of proteins are called amino acids because they contain an amino and a carboxyl group.

A **phosphate group** consists of a phophorus atom bonded to four oxygen atoms. It is usually ionized and attached to the carbon skeleton by one of its oxygen atoms. This structure is abbreviated as P in this text. Compounds with phosphate groups are called organic phosphates and are often involved in energy transfers, as is the energy-rich compound ATP, shown in the table.

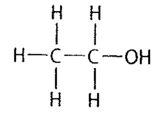
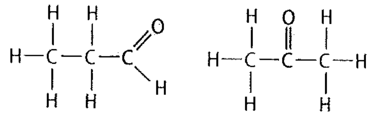
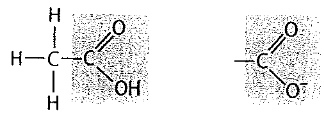
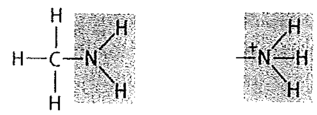
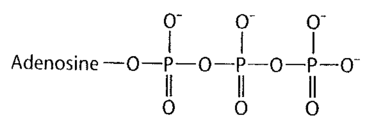
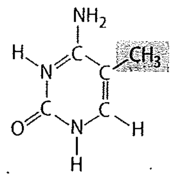
A **methyl group** consists of a carbon bonded to three hydrogens. Compounds with methyl groups are called methylated compounds. The addition of a methyl group to the component of DNA shown in the table affects the expression of genes.

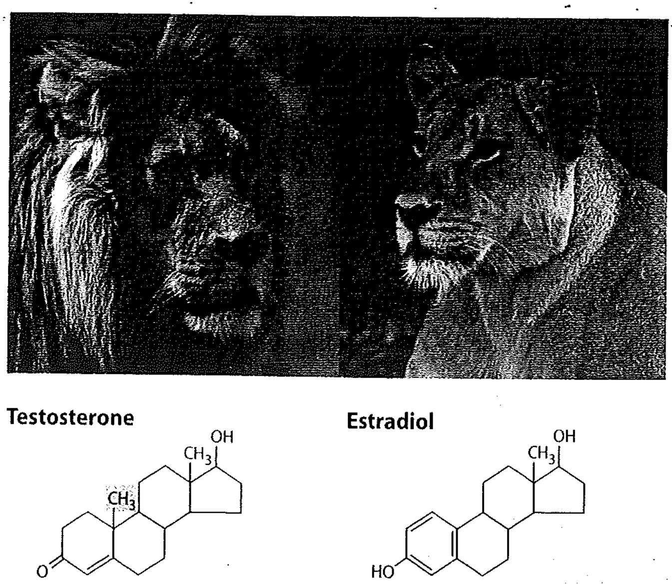
Figure 2.2 shows how a small difference in chemical groups can lead to a big difference in body form and behavior. The male and female sex hormones shown here differ only in the groups highlighted with colored boxes. These subtle differences result in the different actions of these molecules, which help produce the contrasting features of males and females in lions and other vertebrates. Keeping in mind this basic scheme—carbon skeletons with chemical groups—we are now ready to see how our cells make large molecules out of smaller ones.

? Identify the chemical groups that do *not* contain carbon.

The hydroxyl, amino, and phosphate groups.

TABLE 2.2 | IMPORTANT CHEMICAL GROUPS OF ORGANIC COMPOUNDS

Chemical Group	Examples
Hydroxyl group $-OH$	 Alcohol
Carbonyl group $>C=O$	 Aldehyde; Ketone
Carboxyl group $-COOH$	 Carboxylic acid; Ionized
Amino group $-NH_2$	 Amine; Ionized
Phosphate group $-OPO_3^{2-}$	 Organic phosphate
Methyl group $-CH_3$	 Methylated compound

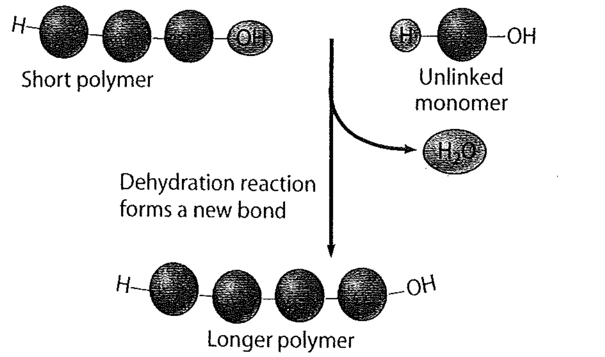


▲ **Figure 2.2** Differences in the chemical groups of sex hormones

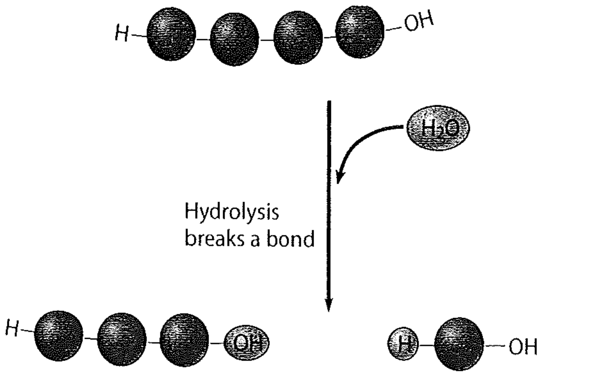
2.3 Cells make a huge number of large molecules from a limited set of small molecules

Given the rich complexity of life on Earth, we might expect there to be an enormous diversity of types of molecules. Remarkably, however, the important molecules of all living things—from bacteria to elephants—fall into just four main classes: carbohydrates, lipids, proteins, and nucleic acids. On a molecular scale, molecules of three of these classes—carbohydrates, proteins, and nucleic acids—may be gigantic; in fact, biologists call them **macromolecules**. For example, a protein may consist of thousands of atoms. How does a cell make such a huge molecule?

Cells make most of their macromolecules by joining smaller molecules into chains called **polymers** (from the Greek *polys*, many, and *meros*, part). A polymer is a large molecule consisting of many identical or similar building blocks strung together, much as a train consists of a chain of cars. The building blocks of polymers are called **monomers**.



▲ **Figure 2.3A** Dehydration reaction building a polymer chain



▲ **Figure 2.3B** Hydrolysis breaking down a polymer

Making Polymers Cells link monomers together to form polymers by a **dehydration reaction**, a reaction that removes a molecule of water. As you can see in **Figure 2.3A**, an unlinked monomer has a hydrogen atom (—H) at one end and a hydroxyl group (—OH) at the other. For each monomer added to a chain, a water molecule (H_2O) is released. Notice in Figure 2.3A that one monomer (the one at the right end of the short polymer in this example) loses a hydroxyl group and the other monomer loses a hydrogen atom to form H_2O. As this occurs, a new covalent bond forms, linking the two monomers. Dehydration reactions are the same regardless of the specific monomers and the type of polymer the cell is producing.

Breaking Polymers Cells not only make macromolecules but also have to break them down. For example, most of the organic molecules in your food are in the form of polymers that are much too large to enter your cells. You must digest these polymers to make their monomers available to your cells. This digestion process is called **hydrolysis**. Essentially the reverse of a dehydration reaction, hydrolysis means to break (*lyse*) with water (*hydro-*). As **Figure 2.3B** shows, the bond between monomers is broken by the addition of a water molecule, with the hydroxyl group from the water attaching to one monomer and a hydrogen attaching to the adjacent monomer.

The lactose-intolerant individuals you learned about in the chapter introduction are unable to hydrolyze such a bond in the sugar lactose because they lack the enzyme lactase. Both dehydration reactions and hydrolysis require the help of enzymes to make and break bonds. **Enzymes** are specialized macromolecules that speed up chemical reactions in cells.

The Diversity of Polymers The diversity of macromolecules in the living world is vast. Remarkably, a cell makes all its thousands of different macromolecules from a small list of ingredients—about 40 to 50 common components and a few others that are rare. Proteins, for example, are built from only 20 kinds of amino acids. Your DNA is built from just four kinds of monomers called nucleotides. The key to the great diversity of polymers is arrangement—variation in the sequence in which monomers are strung together.

The variety in polymers accounts for the uniqueness of each organism. The monomers themselves, however, are essentially universal. Your proteins and those of a tree or an ant are assembled from the same 20 amino acids. Life has a simple yet elegant molecular logic: Small molecules common to all organisms are ordered into large molecules, which vary from species to species and even from individual to individual in the same species.

In the remainder of the chapter, we explore each of the four classes of large biological molecules. Like water and simple organic molecules, large biological molecules have unique emergent properties arising from the orderly arrangement of their atoms. As you will see, for these molecules of life, structure and function are inseparable.

? **Suppose you eat some cheese. What reactions must occur for the protein of the cheese to be broken down into its amino acid monomers and then for these monomers to be converted to proteins in your body?**

In digestion, the proteins are broken down into amino acids by hydrolysis. New proteins are formed in your body cells from these monomers in dehydration reactions.

Carbohydrates

2.4 Monosaccharides are the simplest carbohydrates

The name **carbohydrate** refers to a class of molecules ranging from the small sugar molecules dissolved in soft drinks to large polysaccharides, such as the starch molecules we consume in pasta and potatoes.

The carbohydrate monomers (single-unit sugars) are **monosaccharides** (from the Greek *monos*, single, and *sacchar*, sugar). The honey shown in **Figure 2.4A** consists mainly of monosaccharides called glucose and fructose. These and other single-unit sugars can be hooked together by dehydration reactions to form more complex sugars and polysaccharides.

Monosaccharides generally have molecular formulas that are some multiple of CH_2O. For example, the formula for glucose, a common monosaccharide of central importance in the chemistry of life, is $C_6H_{12}O_6$. **Figure 2.4B** illustrates the molecular structure of glucose, with its carbons numbered 1 to 6. This structure also shows the two trademarks of a sugar: a number of hydroxyl groups (—OH) and a carbonyl group ($>$C=O, highlighted in blue). The hydroxyl groups make a sugar an alcohol, and the carbonyl group, depending on its location, makes it either an aldose (an aldehyde sugar) or a ketose (a ketone sugar). As you see in Figure 2.4B, glucose is an aldose and fructose is a ketose. (Note that most names for sugars end in *-ose*. Also, as you saw with the enzyme lactase that digests lactose, the names for most enzymes end in *-ase*.)

If you count the numbers of different atoms in the fructose molecule in Figure 2.4B, you will find that its molecular formula is $C_6H_{12}O_6$, identical to that of glucose. Thus, glucose and fructose are isomers; they differ only in the arrangement of their atoms (in this case, the positions of the carbonyl groups). Seemingly minor differences like this give isomers different properties, such as how they react with other molecules. These differences also make fructose taste considerably sweeter than glucose.

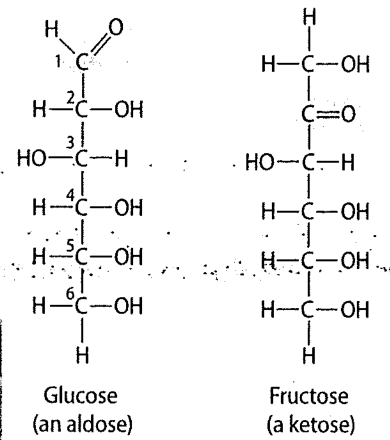
The carbon skeletons of both glucose and fructose are six carbon atoms long. Other monosaccharides may have three to seven carbons. Five-carbon sugars, called pentoses, and six-carbon sugars, called hexoses, are among the most common.

It is convenient to draw sugars as if their carbon skeletons were linear, but in aqueous solutions, many monosaccharides form rings, as shown for glucose in **Figure 2.4C**. To form the glucose ring, carbon 1 bonds to the oxygen attached to carbon 5. As shown in the middle representation, the ring diagram of glucose and other sugars may be abbreviated by not showing the carbon atoms at the corners of the ring. Also, the bonds in the ring are often drawn with varied thickness, indicating that the ring is a relatively flat structure with attached atoms extending above and below it. The simplified ring symbol on the right is often used in this book to represent glucose.

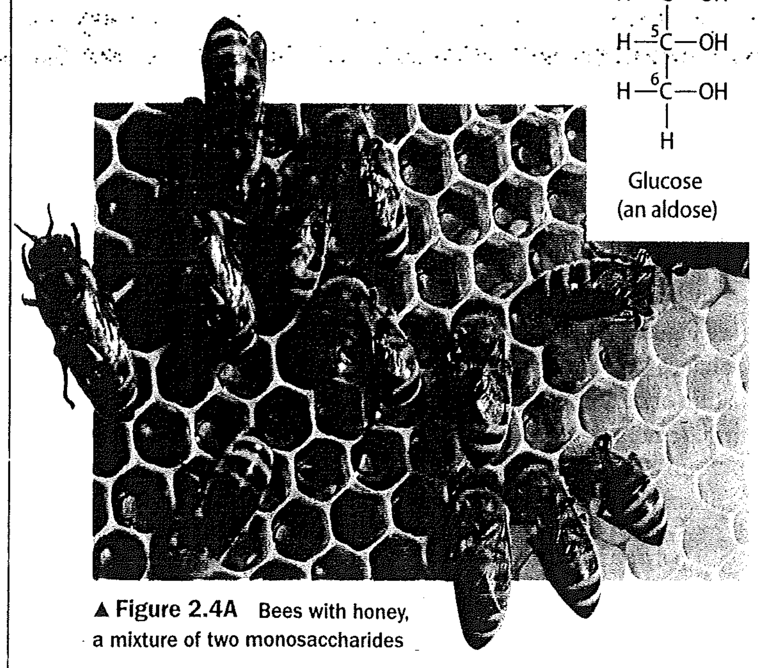
Monosaccharides, particularly glucose, are the main fuel molecules for cellular work. Because cells release energy from glucose when they break it down, an aqueous solution of glucose (often called dextrose) may be injected into the bloodstream of sick or injured patients; the glucose provides an immediate energy source to tissues in need of repair. Cells also use the carbon skeletons of monosaccharides as raw material for making other kinds of organic molecules, such as amino acids and fatty acids. Sugars not used in these ways may be incorporated into disaccharides and polysaccharides, as we see next.

? **Write the formula for a monosaccharide that has three carbons.**

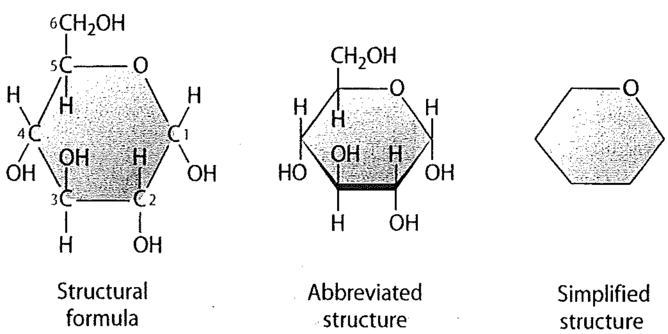
$C_3H_6O_3$



◀ **Figure 2.4B** Structures of glucose and fructose



▲ **Figure 2.4A** Bees with honey, a mixture of two monosaccharides



▲ **Figure 2.4C** Three representations of the ring form of glucose

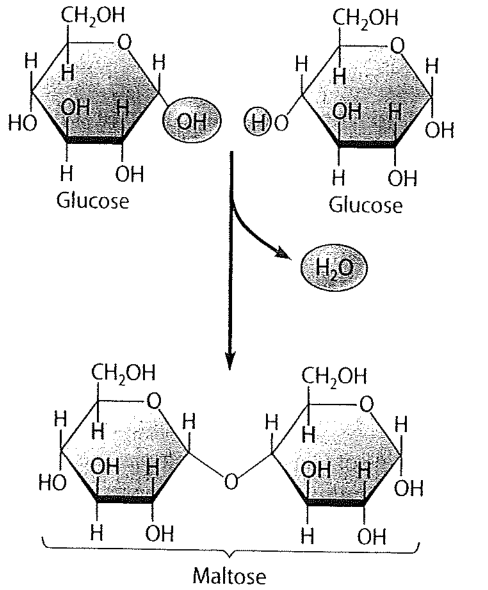
2.5 Two monosaccharides are linked to form a disaccharide

Cells construct a **disaccharide** from two monosaccharide monomers by a dehydration reaction. **Figure 2.5** shows how maltose, also called malt sugar, is formed from two glucose monomers. One monomer gives up a hydroxyl group and the other gives up a hydrogen atom from a hydroxyl group. As H_2O is released, an oxygen atom is left, linking the two monomers. Maltose, which is common in germinating seeds, is used in making beer, malted milk shakes, and malted milk candy.

The most common disaccharide is sucrose, which is made of a glucose monomer linked to a fructose monomer. Transported in plant sap, sucrose provides a source of energy and raw materials to all the parts of the plant. We extract it from the stems of sugarcane or the roots of sugar beets to use as table sugar.

? Lactose, as you read in the chapter introduction, is the disaccharide sugar in milk. It is formed from glucose and galactose. The formula for both these monosaccharides is $C_6H_{12}O_6$. What is the formula for lactose?

$C_{12}H_{22}O_{11}$



▲ **Figure 2.5** Disaccharide formation by a dehydration reaction

2.6 Polysaccharides are long chains of sugar units

Polysaccharides are macromolecules, polymers of hundreds to thousands of monosaccharides linked together by dehydration reactions. Polysaccharides may function as storage molecules or as structural compounds. **Figure 2.6** illustrates three common types of polysaccharides: starch, glycogen, and cellulose.

Starch, a storage polysaccharide in plants, consists entirely of glucose monomers. Starch molecules coil into a helical shape and may be unbranched (as shown in the figure) or branched. Starch granules serve as carbohydrate "banks" from which plant cells can withdraw glucose for energy or building materials. Humans and most other animals have enzymes that can hydrolyze plant starch to glucose. Potatoes and grains, such as wheat, corn, and rice, are the major sources of starch in the human diet.

Animals store glucose in a different form of polysaccharide, called **glycogen**. Glycogen is more highly branched than starch, as shown in the figure. Most of your glycogen is stored as granules in your liver and muscle cells, which hydrolyze the glycogen to release glucose when it is needed.

Cellulose, the most abundant organic compound on Earth, is a major component of the tough walls that enclose plant cells. Cellulose is also a polymer of glucose, but its monomers are linked together in a different orientation. (Carefully compare the oxygen "bridges" highlighted in yellow between glucose monomers in starch, glycogen, and cellulose in the figure.) Arranged parallel to each other, cellulose molecules are joined by hydrogen bonds, forming cable-like microfibrils. Layers of microfibrils combine with other polymers, producing strong support for trees and structures we build with lumber.

Animals do not have enzymes that can hydrolyze the glucose linkages in cellulose. Therefore, cellulose is not a nutrient for humans, although it does contribute to digestive system health. The cellulose that passes unchanged through your digestive tract is referred to as "insoluble fiber." Fresh fruits, vegetables, and grains are rich in fiber.

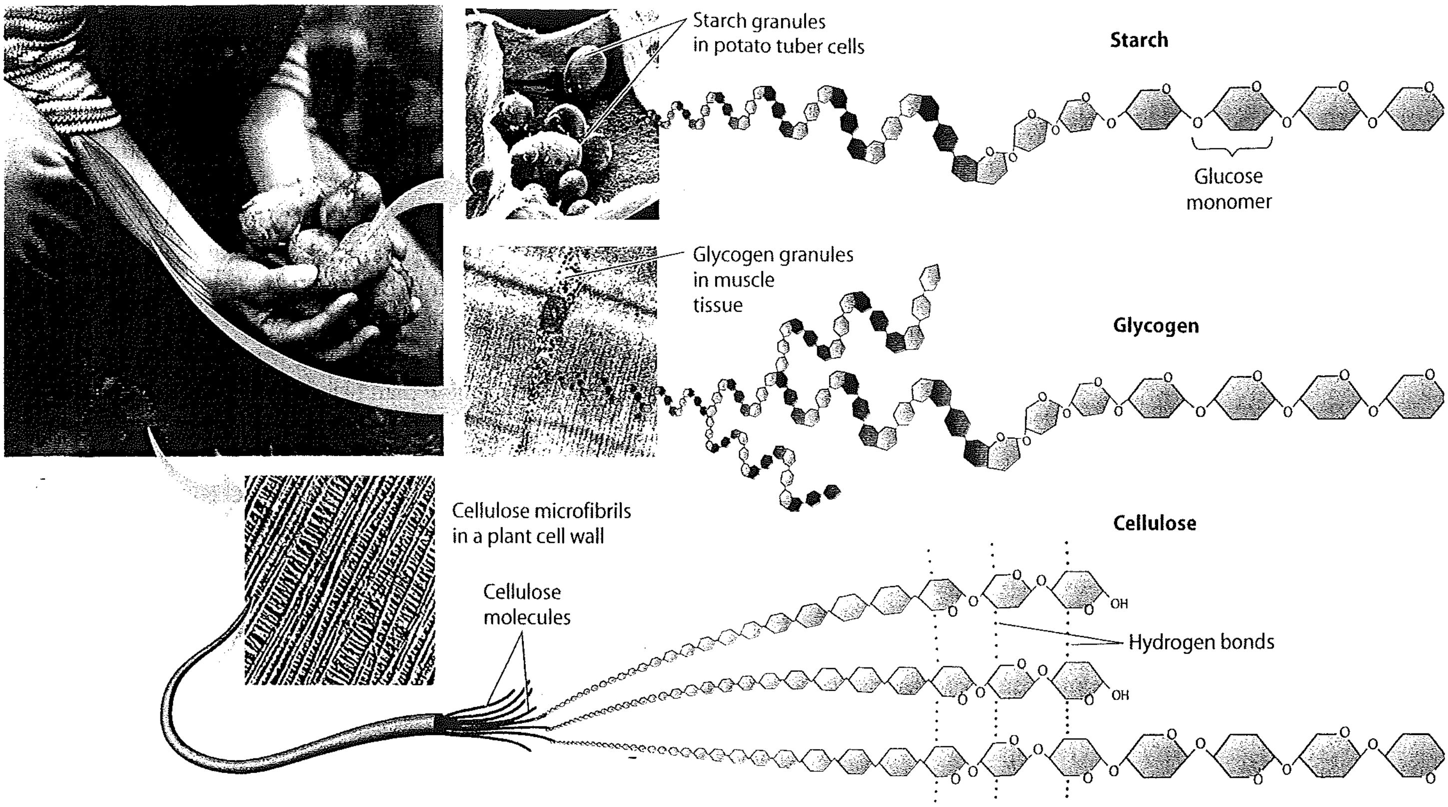
Some microorganisms do have enzymes that can hydrolyze cellulose. Cows and termites house such microorganisms in their digestive tracts and are thus able to derive energy from cellulose. Decomposing fungi also digest cellulose, helping to recycle its chemical elements within ecosystems.

Another structural polysaccharide, **chitin**, is used by insects and crustaceans to build their exoskeleton, the hard case enclosing the animal. Chitin is also found in the cell walls of fungi. Humans use chitin to make a strong and flexible surgical thread that decomposes after a wound or incision heals.

Almost all carbohydrates are hydrophilic owing to the many hydroxyl groups attached to their sugar monomers (see Figure 2.4B). Thus, cotton bath towels, which are mostly cellulose, are quite water absorbent due to the water-loving nature of cellulose. Next we look at a class of macromolecules that are not hydrophilic.

? Compare and contrast starch and cellulose, two plant polysaccharides.

Both are polymers of glucose, but the bonds between glucose monomers have different shapes. Starch functions mainly for sugar storage. Cellulose is a structural polysaccharide that is the main material of plant cell walls.



▲ **Figure 2.6** Polysaccharides

Lipids

2.7 Fats are lipids that are mostly energy-storage molecules

Lipids are diverse compounds that are grouped together because they share one trait: They do not mix well with water. Lipids consist mainly of carbon and hydrogen atoms linked by nonpolar covalent bonds. In contrast to carbohydrates and most other biological molecules, lipids are **hydrophobic** (water-fearing). You can see this chemical behavior in an unshaken bottle of salad dressing: The oil (a type of lipid) separates from the vinegar (which is mostly water). The oils that ducks spread on their feathers make the feathers repel water (**Figure 2.7A**), which helps such waterfowl stay afloat.

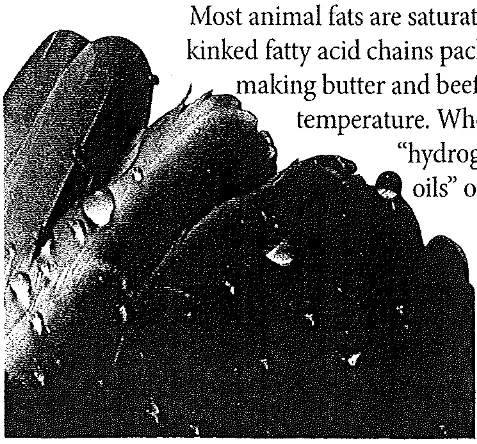
Lipids also differ from carbohydrates, proteins, and nucleic acids in that they are neither huge macromolecules nor polymers built from similar monomers. You will see that lipids vary a great deal in structure and function. In this and the next two modules, we will consider three types of lipids: fats, phospholipids, and steroids.

A **fat** is a large lipid made from two kinds of smaller molecules: glycerol and fatty acids. Shown at the top in **Figure 2.7B**, glycerol is an alcohol with three carbons, each bearing a hydroxyl group (—OH). A fatty acid consists of a carboxyl group (the functional group that gives these molecules the name fatty *acid*, —COOH) and a hydrocarbon chain, usually 16 or 18 carbon atoms in length. The nonpolar hydrocarbon chains are the reason fats are hydrophobic.

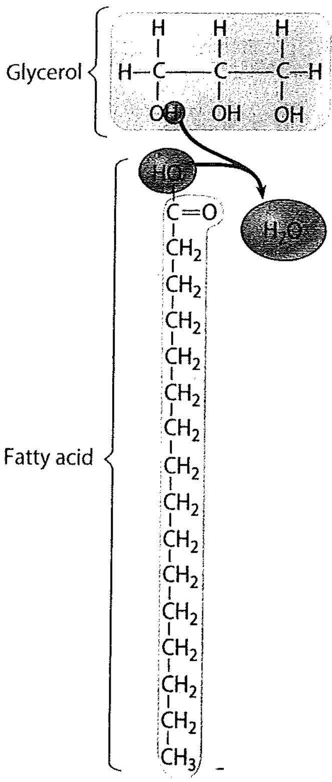
Figure 2.7B shows how one fatty acid molecule can link to a glycerol molecule by a dehydration reaction. Linking three fatty acids to glycerol produces a at, as illustrated in **Figure 2.7C**. A synonym for fat is *triglyceride*, a term you may see on food labels or on medical tests for fat in the blood.

Some fatty acids contain one or more double bonds, which cause kinks (or bends) in the carbon chain. See the third fatty acid in Figure 2.7C. Such an **unsaturated fatty acid** has one fewer hydrogen atom on each carbon of the double bond. Fatty acids with no double bonds in their hydrocarbon chain have the maximum number of hydrogen atoms (are "saturated" with hydrogens) and are called **saturated fatty acids**. The kinks in unsaturated fatty acids prevent fats containing them from packing tightly together and solidifying at room temperature. Corn oil, olive oil, and other vegetable oils are called unsaturated fats.

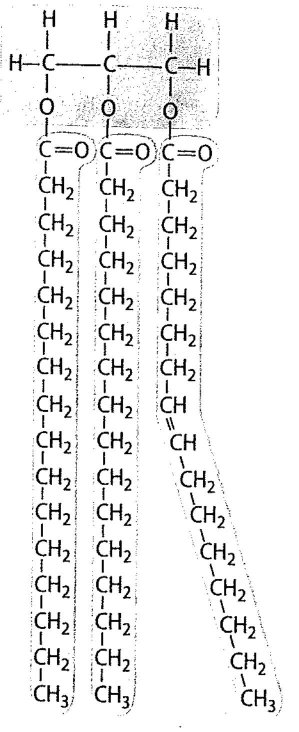
Most animal fats are saturated. Their unkinked fatty acid chains pack closely together, making butter and beef fat solid at room temperature. When you see "hydrogenated vegetable oils" on a margarine



◀ **Figure 2.7A** Water beading on the oily coating of feathers



▲ **Figure 2.7B** A dehydration reaction linking a fatty acid molecule to a glycerol molecule



▲ **Figure 2.7C** A fat molecule (triglyceride) consisting of three fatty acids linked to glycerol

label, it means that unsaturated fats have been converted to saturated fats by adding hydrogen. Unfortunately, hydrogenation also creates **trans fats**, a form of fat that recent research associates with health risks. Diets rich in saturated fats and trans fats may contribute to cardiovascular disease by promoting atherosclerosis. In this condition, lipid-containing deposits called plaques build up within the walls of blood vessels, reducing blood flow. Unsaturated fatty acids called omega-3 fatty acids are found in certain nuts, plant oils, and fatty fish and appear to protect against cardiovascular disease.

The main function of fats is long-term energy storage. A gram of fat stores more than twice as much energy as a gram of polysaccharide. For immobile plants, the bulky energy storage form of starch is not a problem. (Vegetable oils are generally obtained from seeds, where more compact energy storage is a benefit.) A mobile animal, such as a duck or a human, can get around much more easily carrying its energy stores in the form of fat. Of course, the downside of this energy-packed storage form is that it takes more effort for a person to "burn off" excess fat. In addition to storing energy, fatty tissue cushions vital organs and insulates the body.

? How do you think the structure of a monounsaturated fat differs from a polyunsaturated fat?

A monounsaturated fat has a fatty acid with a single double bond in its carbon chain. A polyunsaturated fat has a fatty acid with several double bonds.

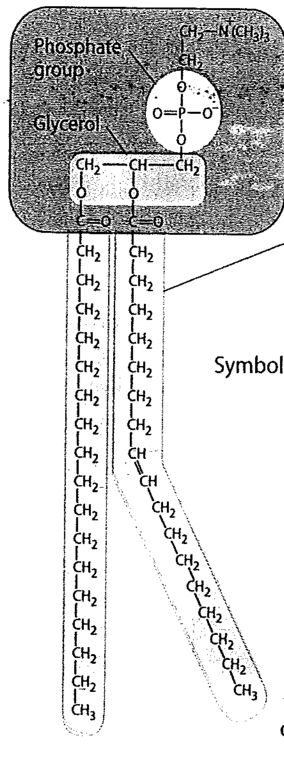
2.8 Phospholipids and steroids are important lipids with a variety of functions

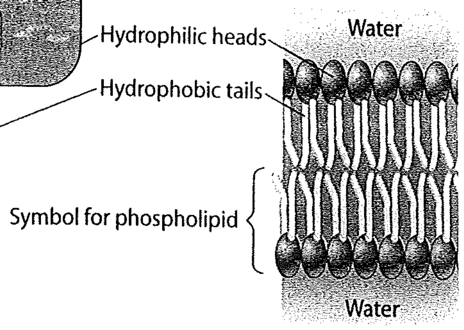
Cells could not exist without **phospholipids**, the major component of cell membranes. Phospholipids are structurally similar to fats, but they contain only two fatty acids attached to glycerol instead of three. As shown in **Figure 2.8A**, a negatively charged phosphate group (shown as a yellow circle in the figure and linked to another small molecule) is attached to glycerol's third carbon. (Note that glycerol is shown in orange.) The structure of phospholipids provides a classic example of how form fits function. The hydrophilic and hydrophobic ends of multiple molecules assemble in a bilayer of phospholipids to form a membrane (**Figure 2.8B**). The hydrophobic tails of the fatty acids cluster in the center, and the hydrophilic phosphate heads face the watery environment on either side of the membrane. Each gray-headed, yellow-tailed structure in the membrane shown here represents a phospholipid; this symbol is used throughout this book. We will explore the structure and function of biological membranes further in Chapter 3.

Steroids are lipids in which the carbon skeleton contains four fused rings, as shown in the structural formula of cholesterol in **Figure 2.8C**. (The diagram omits the carbons making up the rings and most of the chain and also their attached hydrogens.) **Cholesterol** is a common component in animal cell membranes, and animal cells also use it as a starting material for making other steroids, including sex hormones. Different steroids vary in the chemical groups attached to the rings, as you saw in Figure 2.2. Too much cholesterol in the blood may contribute to atherosclerosis.

? Compare the structure of a phospholipid with that of a fat (triglyceride).

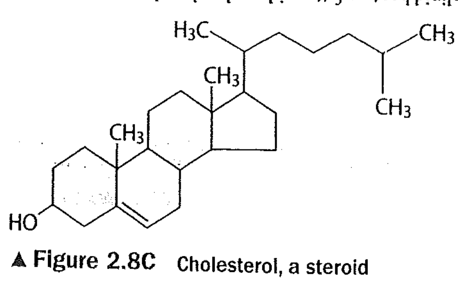
A phospholipid has two fatty acids and a phosphate group attached to glycerol. Three fatty acids are attached to the glycerol of a fat molecule.





▲ **Figure 2.8B** Section of a phospholipid membrane

◄ **Figure 2.8A** Chemical structure of a phospholipid molecule

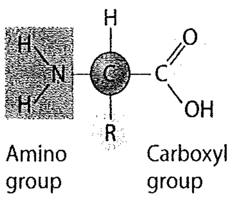


▲ **Figure 2.8C** Cholesterol, a steroid

Proteins

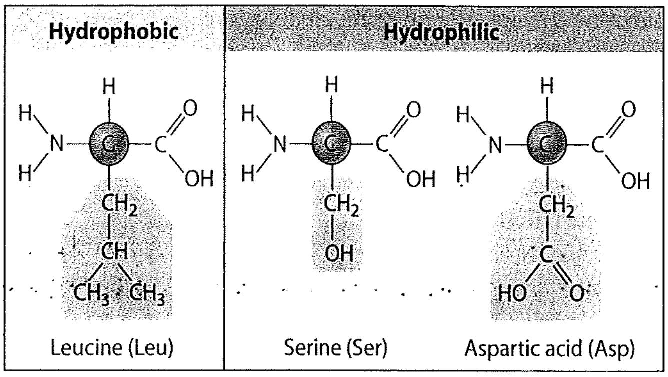
2.9 Proteins are made from amino acids linked by peptide bonds

Nearly every dynamic function in your body depends on proteins. You have tens of thousands of different proteins, each with a specific structure and function. Of all of life's molecules, proteins are structurally the most elaborate and diverse. A **protein** is a polymer of amino acids. Protein diversity is based on differing arrangements of a common set of just 20 amino acid monomers.



▲ **Figure 2.9A** General structure of an amino acid

Amino acids all have an amino group and a carboxyl group (which makes it an acid, hence the name amino *acid*). As you can see in the general structure shown in **Figure 2.9A**, both of these functional groups are covalently bonded to a central carbon atom, called the alpha carbon. Also bonded to the alpha carbon is a hydrogen atom and a chemical group symbolized by the letter R. The R group, also called the side chain, differs with each amino acid. In the simplest amino acid (glycine), the R group is just a hydrogen atom. In all others, such as those shown in **Figure 2.9B**, the R group consists of one or more carbon atoms with various chemical groups attached. The composition and structure of the R group determines the specific properties of each of the 20 amino acids that are found in proteins.



▲ **Figure 2.9B** Examples of amino acids with hydrophobic and hydrophilic R groups

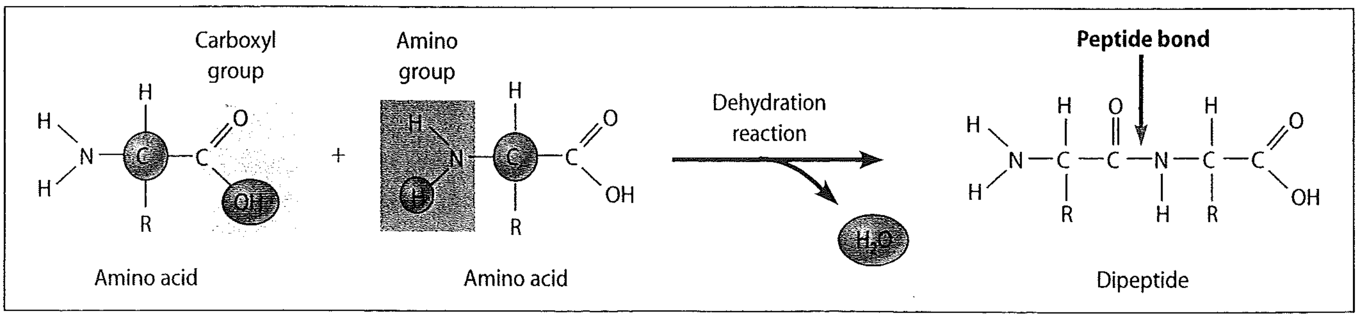
The amino acids in Figure 2.9B represent two main types, hydrophobic and hydrophilic. Leucine (abbreviated Leu) is an example of an amino acid in which the R group is nonpolar and hydrophobic. Serine (Ser), with a hydroxyl group in its R group, is an example of an amino acid with a polar, hydrophilic R group. Aspartic acid (Asp) is acidic and negatively charged at the pH of a cell. (Indeed, all the amino and carboxyl groups of amino acids are usually ionized at cellular pH, as shown in Table 2.2.) Other amino acids have basic R groups and are positively charged. Amino acids with polar and charged R groups help proteins dissolve in the aqueous solutions inside cells.

Now that we have examined amino acids, let's see how they are linked to form polymers. Can you guess? Cells join amino acids together in a dehydration reaction that links the carboxyl group of one amino acid to the amino group of the next amino acid as a water molecule is removed **(Figure 2.9C)**. The resulting covalent linkage is called a **peptide bond**. The product of the reaction shown in the figure is called a *di*peptide, because it was made from *two* amino acids. Additional amino acids can be added by the same process to form a chain of amino acids, a **polypeptide**. To release amino acids from the polypeptide by hydrolysis, a molecule of H_2O must be added back to break each peptide bond.

How is it possible to make thousands of different kinds of proteins from just 20 amino acids? The answer has to do with sequence. You know that thousands of English words can be made by varying the sequence of letters and word length. Although the protein "alphabet" is slightly smaller (just 20 "letters," rather than 26), the "words" are much longer. Most polypeptides are at least 100 amino acids in length; some are 1,000 or more. Each polypeptide has a unique sequence of amino acids. But a long polypeptide chain of specific sequence is not the same as a protein, any more than a long strand of yarn is the same as a sweater that can be knit from that yarn. A functioning protein is one or more polypeptide chains precisely coiled, twisted, and folded into a unique three-dimensional shape.

? In what way is the production of a dipeptide similar to the production of a disaccharide?

In both cases, the monomers are joined by a dehydration reaction.



▲ **Figure 2.9C** Peptide bond formation

2.10 A protein's specific shape determines its function

What do the tens of thousands of different proteins in your body do? Probably their most important role is as *enzymes*, the chemical catalysts that speed and regulate virtually all chemical reactions in cells. Lactase, which you read about in the chapter introduction, is just one of thousands of different enzymes that may be produced by cells.

Structural proteins are found in hair and the fibers that make up connective tissues such as tendons and ligaments. Muscle cells are packed with *contractile proteins.*

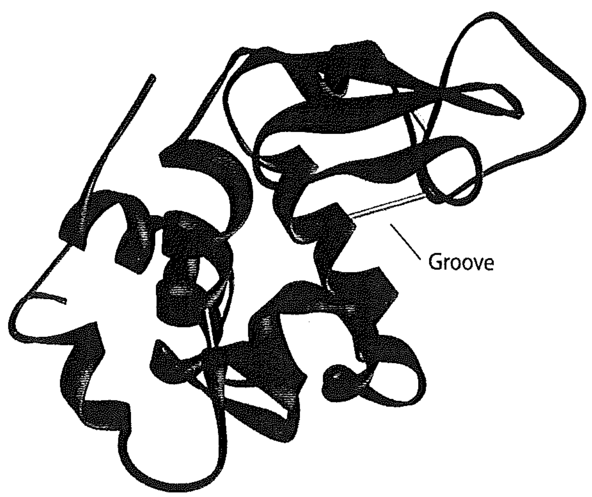
Other types of proteins include *defensive proteins*, such as the antibodies of the immune system, and *signal proteins*, such as many of the hormones and other chemical messengers that help coordinate body activities by facilitating communication between cells. *Receptor proteins* may be built into cell membranes and transmit signals into cells. Hemoglobin in red blood cells is a *transport protein* that delivers O_2 to working muscles and tissues throughout the body. Other transport proteins move sugar molecules into cells for energy. Some proteins are *storage proteins*, such as ovalbumin, the protein of egg white, which serves as a source of amino acids for developing embryos. Milk proteins provide amino acids for baby mammals, and plant seeds contain storage proteins that nourish developing plant embryos.

The functions of all these different types of proteins depend on their specific shape. **Figure 2.10A** shows a ribbon model of lysozyme, an enzyme found in your sweat, tears, and saliva. Lysozyme consists of one long polypeptide, represented by the purple ribbon. Lysozyme's general shape is called globular. This overall shape is more apparent in **Figure 2.10B**, a space-filling model of lysozyme. In that model, the colors represent the different atoms of carbon, oxygen, nitrogen, and hydrogen. The barely visible yellow balls are sulfur atoms that form the stabilizing bonds shown as yellow lines in the ribbon model. Most enzymes and other proteins are globular. Structural proteins, such as those making up hair, tendons, and ligaments, are typically long and thin and are called fibrous proteins.

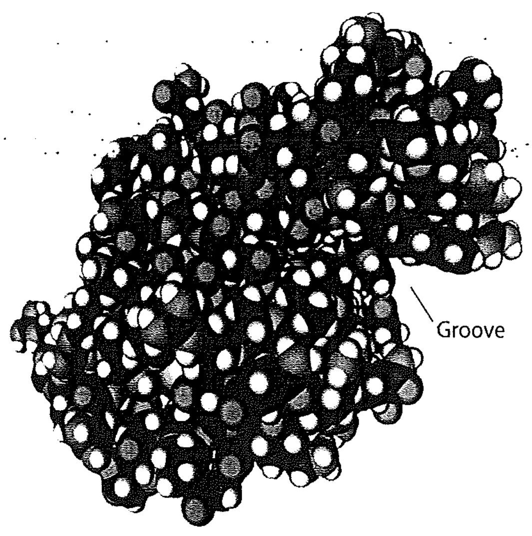
Descriptions such as globular and fibrous refer to a protein's general shape. Each protein also has a much more specific shape. The coils and twists of lysozyme's polypeptide ribbon appear haphazard, but they represent the molecule's specific, three-dimensional shape, and this shape is what determines its specific function. Nearly all proteins must recognize and bind to some other molecule to function. Lysozyme, for example, can destroy bacterial cells, but first it must bind to specific molecules on the bacterial cell surface. Lysozyme's specific shape enables it to recognize and attach to its molecular target, which fits into the groove you see on the right in the figures.

The dependence of protein function on a protein's specific shape becomes clear when proteins are altered. In a process called **denaturation**, polypeptide chains unravel, losing their specific shape and, as a result, their function. Changes in salt concentration and pH can denature many proteins, as can excessive heat. For example, visualize what happens when you fry an egg. Heat quickly denatures the clear proteins surrounding the yolk, making them solid, white, and opaque. One of the reasons why extremely high fevers are so dangerous is that some proteins in the body become denatured and cannot function.

Given the proper cellular environment, a newly synthesized polypeptide chain spontaneously folds into its functional shape. We examine the four levels of a protein's structure next.



▲ **Figure 2.10A** Ribbon model of the protein lysozyme



▲ **Figure 2.10B** Space-filling model of the protein lysozyme

? Why does a denatured protein no longer function normally?

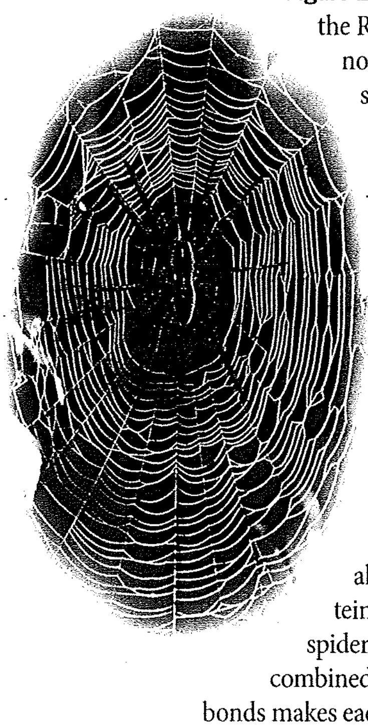
The function of each protein is a consequence of its specific shape, which is lost when a protein denatures.

2.11 A protein's shape depends on four levels of structure

Primary Structure The **primary structure** of a protein is its unique sequence of amino acids. As an example, let's consider transthyretin, an important transport protein found in your blood. Its specific shape enables it to transport vitamin A and one of the thyroid hormones throughout your body. A complete molecule of transthyretin has four identical polypeptide chains, each made up of 127 amino acids. **Figure 2.11A**, on the next page, shows part of one of these chains unraveled for a closer look at its primary structure. The three-letter abbreviations represent the specific amino acids that make up the chain.

In order for transthyretin or any other protein to perform its specific function, it must have the correct amino acids arranged in a precise order. The primary structure of a protein is determined by inherited genetic information. Even a slight change in primary structure may affect a protein's overall shape and thus its ability to function. For instance, a single amino acid change in hemoglobin, the oxygen-carrying blood protein, causes sickle-cell disease, a serious blood disorder.

Secondary Structure In the second level of protein structure, parts of the polypeptide coil or fold into local patterns called **secondary structure.** Coiling of a polypeptide chain results in a secondary structure called an alpha helix; a certain kind of folding leads to a secondary structure called a beta pleated sheet. Both of these patterns are maintained by regularly spaced hydrogen bonds between hydrogen atoms and oxygen atoms along the backbone of the polypeptide chain. Each hydrogen bond is represented in **Figure 2.11B** by a row of dots. Because the R groups of the amino acids are not involved in forming these secondary structures, they are omitted from the diagrams.



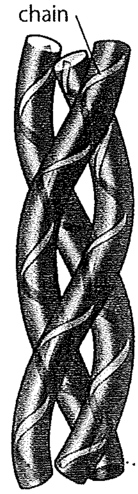
Transthyretin has only one alpha helix region (see **Figure 2.11C**). In contrast, some fibrous proteins, such as the structural protein of hair, have the alpha helix structure over most of their length.

Beta pleated sheets make up the core of many globular proteins, as is the case for transthyretin. Pleated sheets also dominate some fibrous proteins, including the silk protein of a spider's web, shown to the left. The combined strength of so many hydrogen bonds makes each silk fiber stronger than a steel strand of the same weight. Potential uses of spider silk proteins include surgical thread, fishing line, and bulletproof vests.

Tertiary Structure The term **tertiary structure** refers to the overall three-dimensional shape of a polypeptide, which, as we've said, determines the function of a protein. As shown in Figure 2.11C, a transthyretin polypeptide has a globular shape, which results from the compact arrangement of its alpha helix region and beta pleated sheet regions.

Here the R groups of the amino acids making up the polypeptide get involved in creating a protein's shape. Tertiary structure results from interactions between these R groups. For example, transthyretin and other proteins found in aqueous solutions are folded so that the hydrophobic R groups are on the inside of the molecule and the hydrophilic R groups on the outside, exposed to water. In addition to the clustering of hydrophobic groups, hydrogen bonding between polar side chains and ionic bonding of some of the charged (ionized) R groups help maintain the tertiary structure. A protein's shape may be reinforced further by covalent bonds called disulfide bridges. You saw disulfide bridges as the yellow lines in the ribbon model of lysozyme in Figure 2.10A.

Quaternary Structure Many proteins consist of two or more polypeptide chains aggregated into one functional macromolecule. Such proteins have a **quaternary structure**, resulting from the association of these polypeptides, which are known as "subunits." **Figure 2.11D** shows a complete transthyretin molecule with its four identical globular subunits.



Collagen

Another example of a protein with quaternary structure is collagen, shown to the right. Collagen is a fibrous protein with three helical polypeptides intertwined into a larger triple helix. This arrangement gives the long fibers great strength, suited to their function as the girders of connective tissue in skin, bone, tendons, and ligaments. Collagen accounts for 40% of the protein in your body.

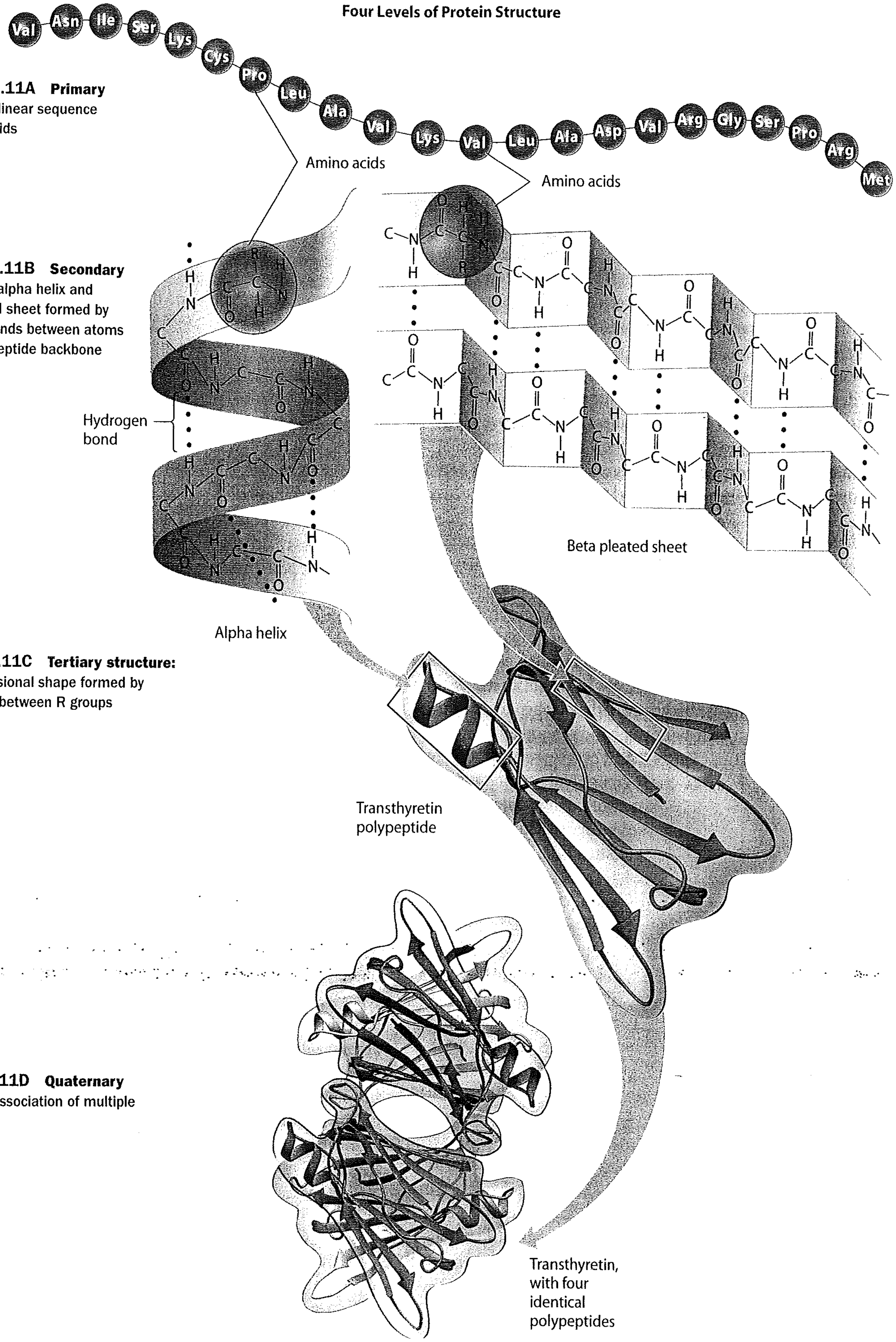
Many other proteins have subunits that are different from one another. For example, the oxygen-transporting molecule hemoglobin has four polypeptides of two distinct types. Each polypeptide has a nonprotein attachment, called a heme, with an iron atom that binds oxygen.

What happens if a protein folds incorrectly? Many diseases, such as Alzheimer's and Parkinson's, involve an accumulation of misfolded proteins. Prions are infectious misshapen proteins that are associated with serious degenerative brain diseases such as mad cow disease. Such diseases reinforce the theme that structure fits function: A protein's unique three-dimensional shape determines its proper functioning.

? If a genetic mutation changes the primary structure of a protein, how might this destroy the protein's function?

Primary structure, the amino acid sequence, affects the secondary structure, which affects the tertiary structure, which affects the quaternary structure (if any). Thus, primary structure determines the shape of a protein and the function of a protein. A shape change could eliminate function.

Four Levels of Protein Structure



▶ **Figure 2.11A Primary structure:** linear sequence of amino acids

▶ **Figure 2.11B Secondary structure:** alpha helix and beta pleated sheet formed by hydrogen bonds between atoms of the polypeptide backbone

▶ **Figure 2.11C Tertiary structure:** three-dimensional shape formed by interactions between R groups

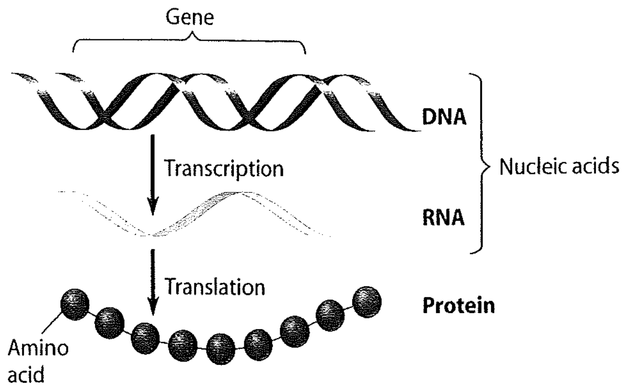
▶ **Figure 2.11D Quaternary structure:** association of multiple polypeptides

Nucleic Acids

2.12 DNA and RNA are the two types of nucleic acids

As we just saw, the primary structure of a polypeptide determines the shape of a protein. But what determines the primary structure? The amino acid sequence of a polypeptide is programmed by a discrete unit of inheritance known as a **gene**. Genes consist of **DNA (deoxyribonucleic acid)**, one of the two types of polymers called **nucleic acids**. The name *nucleic* comes from their location in the nuclei of eukaryotic cells. The genetic material that humans and other organisms inherit from their parents consists of DNA. Unique among molecules, DNA provides directions for its own replication. Thus, as a cell divides, its genetic instructions are passed to each daughter cell. These instructions program all of a cell's activities by directing the synthesis of proteins.

The genes present in DNA do not build proteins directly. They work through an intermediary—the second type of nucleic acid, known as **ribonucleic acid (RNA)**. **Figure 2.12** illustrates the main roles of these two types of nucleic acids in the production of proteins. In the nucleus of a eukaryotic cell, a gene directs the synthesis of an RNA molecule. We say that DNA is transcribed into RNA. The RNA molecule moves out of the nucleus and interacts with the protein-building machinery of the cell. There, the gene's instructions, written in "nucleic acid language," are translated into "protein language," the amino acid sequence of a polypeptide. (In prokaryotic cells, which lack nuclei, both transcription and translation take place within the cytoplasm of the cell.)



▲ **Figure 2.12** The flow of genetic information in the building of a protein

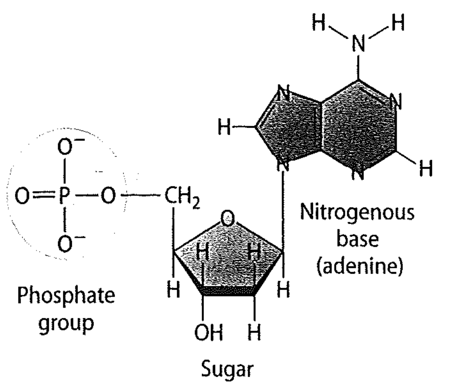
Recent research has found previously unknown types of RNA molecules that play many other roles in the cell. We return to the functions of DNA and RNA later in the book.

How are the two types of nucleic acids functionally related?

The hereditary material of DNA contains the instructions for the primary structure of polypeptides. RNA is the intermediary that conveys those instructions to the protein-making machinery that assembles amino acids in the designated order.

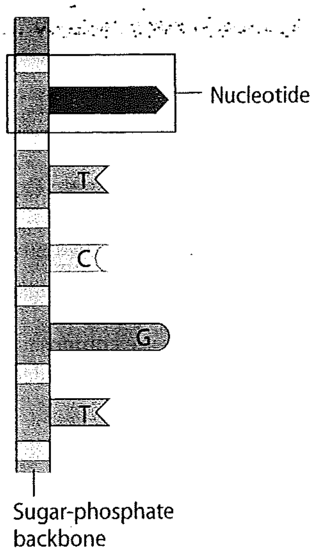
2.13 Nucleic acids are polymers of nucleotides

The monomers that make up nucleic acids are **nucleotides**. As indicated in **Figure 2.13A**, each nucleotide contains three parts. At the center of a nucleotide is a five-carbon sugar (blue); the sugar in DNA is deoxyribose (shown in Figure 2.13A), whereas RNA has a slightly different sugar called ribose. Linked to one side of the sugar in both types of nucleotides is a negatively charged phosphate group (yellow). Linked to the sugar's other side is a nitrogenous base (green), a molecular structure containing nitrogen and carbon. (The nitrogen atoms tend to take up H^+ in aqueous solutions, which explains why it is called a nitrogenous *base*.) Each DNA nucleotide has one of four different nitrogenous bases: adenine (A), thymine (T), cytosine (C), and guanine (G). Thus, all genetic information is written in a four-letter alphabet. RNA nucleotides also contain the bases A, C, and G; but the base uracil (U) is found instead of thymine.



▲ **Figure 2.13A** A nucleotide, consisting of a phosphate group, a sugar, and a nitrogenous base

Like polysaccharides and polypeptides, a nucleic acid polymer—a polynucleotide—is built from its monomers by dehydration reactions. In this process, the sugar of one nucleotide bonds to the phosphate group of the next monomer. The result is a repeating sugar-phosphate backbone in the polymer, as represented by the blue and yellow ribbon in **Figure 2.13B**. (Note that the nitrogenous bases are not part of the backbone.)



▲ **Figure 2.13B** Part of a polynucleotide

RNA usually consists of a single polynucleotide strand, but DNA is a

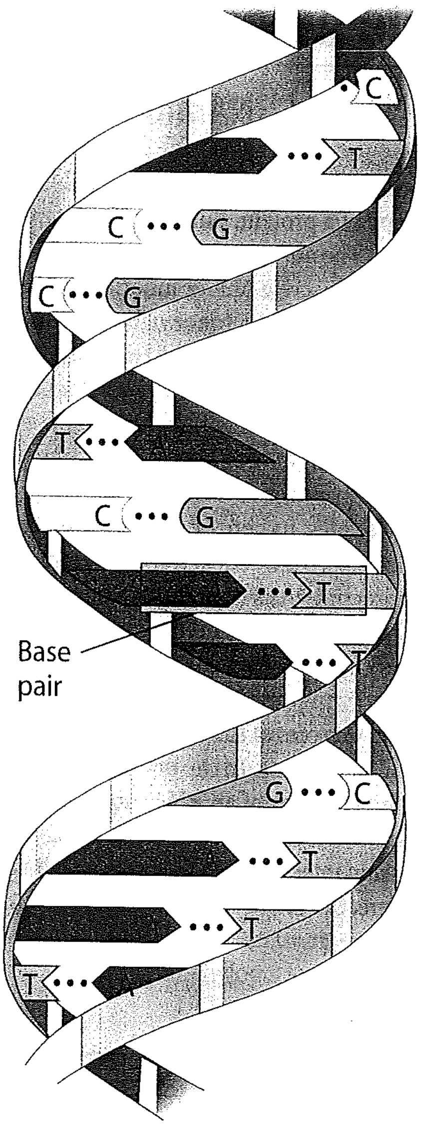
double helix, in which two polynucleotides wrap around each other **(Figure 2.13C)**. The nitrogenous bases protrude from the two sugar-phosphate backbones and pair in the center of the helix. As shown by their diagrammatic shapes in the figure, A always pairs with T, and C always pairs with G. The two DNA chains are held together by hydrogen bonds (indicated by the dotted lines) between their paired bases. These bonds are individually weak, but collectively they zip the two strands together into a very stable double helix. Most DNA molecules have thousands or even millions of base pairs.

Because of the base-pairing rules, the two strands of the double helix are said to be *complementary*, each a predictable counterpart of the other. Thus, if a stretch of nucleotides on one strand has the base sequence –AGCACT–, then the same stretch on the other strand must be –TCGTGA–. Complementary base pairing is the key to how a cell makes two identical copies of each of its DNA molecules every time it divides. Thus, the structure of DNA accounts for its function of transmitting genetic information whenever a cell reproduces. The same base-pairing rules (with the exception that U nucleotides of RNA pair with A nucleotides of DNA) also account for the precise transcription of information from DNA to RNA.

An organism's genes determine the proteins and thus the structures and functions of its body. Let's return to the subject of the chapter introduction—lactose intolerance—to conclude our study of biological molecules. In the next chapter, we move up in the biological hierarchy to the level of the cell.

? What roles do complementary base pairing play in the functioning of nucleic acids?

Complementary base pairing makes possible the precise replication of DNA, ensuring that genetic information is faithfully transmitted every time a cell divides. It also ensures that RNA molecules carry accurate instructions for the synthesis of proteins.



▲ **Figure 2.13C** DNA double helix

CHAPTER 2 REVIEW

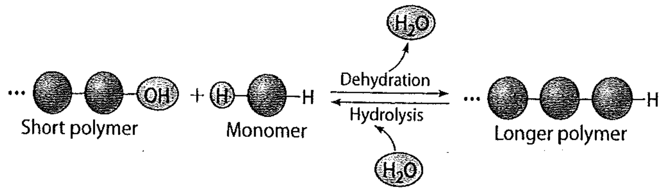
Reviewing the Concepts

Introduction to Organic Compounds (2.1–2.3)

2.1 Life's molecular diversity is based on the properties of carbon. Carbon's ability to bond with four other atoms is the basis for building large and diverse organic compounds. Hydrocarbons are composed of only carbon and hydrogen. Isomers have the same molecular formula but different structures.

2.2 A few chemical groups are key to the functioning of biological molecules. Hydrophilic functional groups give organic molecules specific chemical properties.

2.3 Cells make a huge number of large molecules from a limited set of small molecules.



Carbohydrates (2.4–2.6)

2.4 Monosaccharides are the simplest carbohydrates. A monosaccharide has a formula that is a multiple of CH_2O and contains hydroxyl groups and a carbonyl group.

2.5 Two monosaccharides are linked to form a disaccharide.

2.6 Polysaccharides are long chains of sugar units. Starch and glycogen are storage polysaccharides; cellulose is structural, found in plant cell walls. Chitin is a component of insect exoskeletons and fungal cell walls.

Lipids (2.7–2.8)

2.7 Fats are lipids that are mostly energy-storage molecules. Lipids are diverse, hydrophobic compounds composed largely of carbon and hydrogen. Fats (triglycerides) consist of glycerol linked to three fatty acids. Saturated fatty acids are found in animal fats; unsaturated fatty acids are typical of plant oils.

2.8 Phospholipids and steroids are important lipids with a variety of functions. Phospholipids are components of cell membranes. Steroids include cholesterol and some hormones.

Proteins (2.9–2.11)

2.9 Proteins are made from amino acids linked by peptide bonds. Protein diversity is based on different sequences of amino acids, monomers that contain an amino group, a carboxyl group, an H, and an R group, all attached to a central carbon. The R groups distinguish 20 amino acids, each with specific properties.

2.10 A protein's specific shape determines its function. Proteins are involved in almost all of a cell's activities; as enzymes, they regulate chemical reactions.

2.11 A protein's shape depends on four levels of structure. A protein's primary structure is the sequence of amino acids in its polypeptide chain. Its secondary structure is the coiling or folding of the chain, stabilized by hydrogen bonds. Tertiary structure is the overall three-dimensional shape of a polypeptide, resulting from interactions among R groups. Proteins made of more than one polypeptide have quaternary structure.

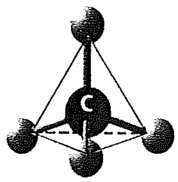
Nucleic Acids (2.12–2.13)

2.12 DNA and RNA are the two types of nucleic acids. DNA and RNA serve as the blueprints for proteins and thus control the life of a cell.

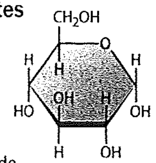
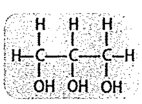
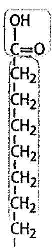
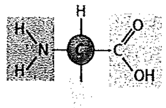
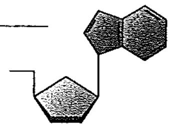
2.13 Nucleic acids are polymers of nucleotides. Nucleotides are composed of a sugar, a phosphate group, and a nitrogenous base. DNA is a double helix; RNA is a single polynucleotide chain.

Connecting the Concepts

1. The diversity of life is staggering. Yet the molecular logic of life is simple and elegant: Small molecules common to all organisms are ordered into unique macromolecules. Explain why carbon is central to this diversity of organic molecules. How do carbon skeletons, chemical groups, monomers, and polymers relate to this molecular logic of life?



2. Complete the table to help review the structures and functions of the four classes of organic molecules.

Classes of Molecules and Their Components	Functions	Examples
Carbohydrates  Monosaccharide	Energy for cell, raw material b. ________ Plant cell support	a. ________ Starch, glycogen c. ________
Lipids (don't form polymers)  Glycerol  Fatty acid Components of a fat molecule	Energy storage e. ________ Hormones	d. ________ Phospholipids f. ________
Proteins g. ________ h. ________  i. ________ Amino acid	j. ________ k. ________ l. ________ Transport Communication n. ________ Storage Receive signals	Lactase Hair, tendons Muscles m. ________ Signal proteins Antibodies Egg albumin Receptor protein
Nucleic Acids p. ________ o. ________  Nucleotide q. ________	Heredity s. ________	r. ________ DNA and RNA

Testing Your Knowledge

Multiple Choice

3. A glucose molecule is to starch as (*Explain your answer.*)
   a. a steroid is to a lipid.
   b. a protein is to an amino acid.
   c. a nucleic acid is to a polypeptide.
   d. a nucleotide is to a nucleic acid.
   e. an amino acid is to a nucleic acid.

4. What makes a fatty acid an acid?
   a. It does not dissolve in water.
   b. It is capable of bonding with other molecules to form a fat.
   c. It has a carboxyl group that donates an H^+ to a solution.
   d. It contains only two oxygen atoms.
   e. It is a polymer made of many smaller subunits.

5. Where in the tertiary structure of a water-soluble protein would you most likely find an amino acid with a hydrophobic R group?
   a. at both ends of the polypeptide chain
   b. on the outside, next to the water
   c. covalently bonded to another R group
   d. on the inside, away from water
   e. hydrogen-bonded to nearby amino acids

6. Cows can derive nutrients from cellulose because
   a. they produce enzymes that recognize the shape of the glucose-glucose bonds and hydrolyze them.
   b. they rechew their cud to break down cellulose fibers.
   c. one of their stomachs contains prokaryotes that can hydrolyze the bonds of cellulose.
   d. their intestinal tract contains termites, which produce enzymes to hydrolyze cellulose.
   e. they convert cellulose to starch and can digest starch.

7. A shortage of phosphorus in the soil would make it especially difficult for a plant to manufacture
   a. DNA.
   b. proteins.
   c. cellulose.
   d. fatty acids.
   e. sucrose.

8. Lipids differ from other large biological molecules in that they
   a. are much larger.
   b. are not polymers.
   c. do not have specific shapes.
   d. are nonpolar and therefore hydrophilic.
   e. contain nitrogen atoms.

9. Of the following functional groups, which is/are polar, tending to make organic compounds hydrophilic?
   a. carbonyl
   b. amino
   c. hydroxyl
   d. carboxyl
   e. all of the above

10. Unsaturated fats
   a. are more common in animals than in plants.
   b. have fewer fatty acid molecules per fat molecule.
   c. are associated with greater health risks than are saturated fats.
   d. have double bonds in their fatty acid chains.
   e. are usually solid at room temperature.

Describing, Comparing, and Explaining

11. List three different kinds of lipids and describe their functions.

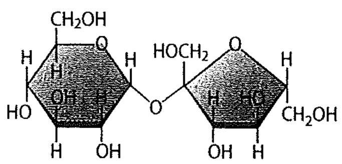
12. Explain why heat, pH changes, and other environmental changes can interfere with a protein's function.

13. How can a cell make many different kinds of protein out of only 20 amino acids? Of the myriad possibilities, how does the cell "know" which proteins to make?

14. Briefly describe the various functions performed by proteins in a cell.

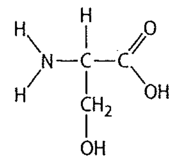
15. Explain how DNA controls the functions of a cell.

16. Sucrose is broken down in your intestine to the monosaccharides glucose and fructose, which are then absorbed into your blood. What is the name of this type of reaction? Using this diagram of sucrose, show how this would occur.



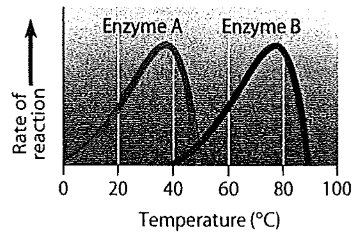
Sucrose

17. Circle and name the functional groups in this organic molecule. What type of compound is this? For which class of macromolecules is it a monomer?



Applying the Concepts

18. Enzymes usually function best at an optimal pH and temperature. The following graph shows the effectiveness of two enzymes at various temperatures.



   a. At which temperature does enzyme A perform best? Enzyme B?
   b. One of these enzymes is found in humans and the other in thermophilic (heat-loving) bacteria. Which enzyme would you predict comes from which organism?
   c. From what you know about enzyme structure, explain why the rate of the reaction catalyzed by enzyme A slows down at temperatures above 40°C (140°F).

19. Some scientists hypothesize that life elsewhere in the universe might be based on the element silicon rather than on carbon. What properties does silicon share with carbon that would make silicon-based life more likely than, for example, neon-based or sulfur-based life?

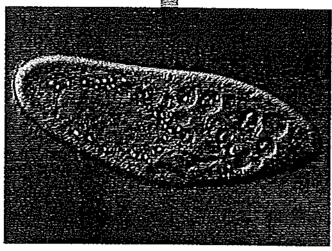
Answers to all questions can be found in Appendix 1.

CHAPTER

3

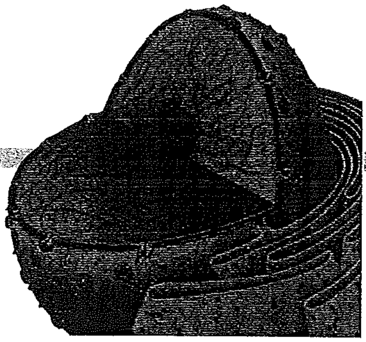
A Tour of the Cell

BIG IDEAS



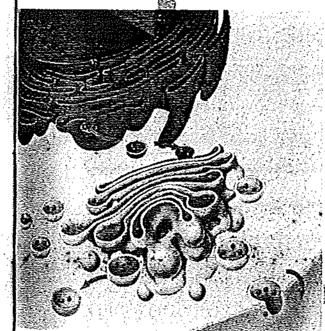
Introduction to the Cell
(3.1–3.3)

Microscopes reveal the structures of cells—the fundamental units of life.



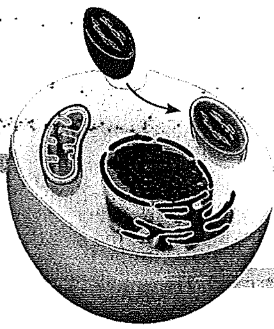
The Nucleus and Ribosomes
(3.4–3.5)

A cell's genetic instructions are housed in the nucleus and carried out by ribosomes.



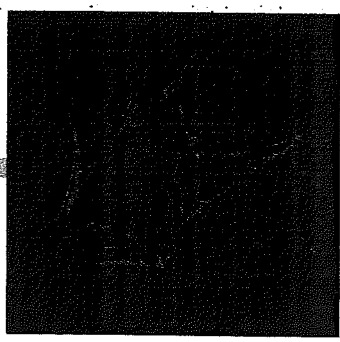
The Endomembrane System
(3.6–3.10)

The endomembrane system participates in the manufacture, distribution, and breakdown of materials.



Energy-Converting Organelles
(3.11–3.12)

Mitochondria in all cells and chloroplasts in plant cells function in energy processing.



The Cytoskeleton and Cell Surfaces
(3.13–3.15)

The cytoskeleton and extracellular components provide support, motility, and functional connections.

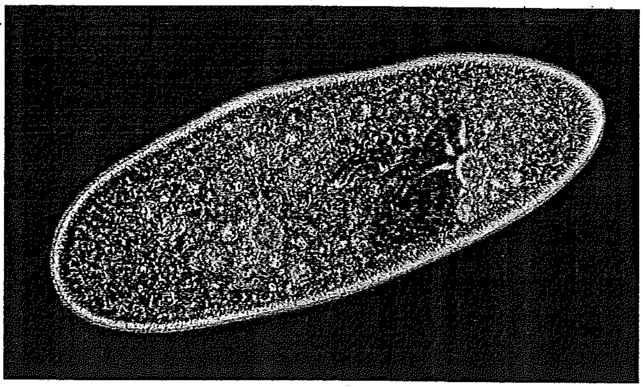
Introduction to the Cell

3.1 Microscopes reveal the world of the cell

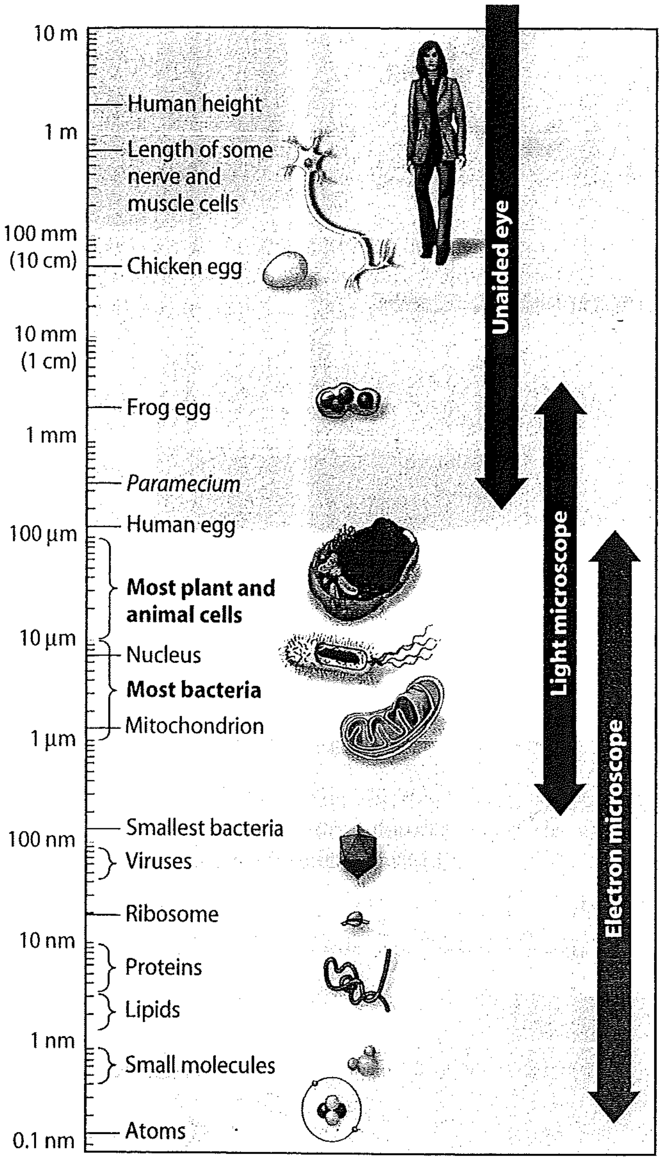
Our understanding of nature often goes hand in hand with the invention and refinement of instruments that extend human senses. Before microscopes were first used in the 17th century, no one knew that living organisms were composed of cells. The first microscopes were light microscopes, like the ones you may use in a biology laboratory. In a **light microscope (LM)**, visible light is passed through a specimen, such as a microorganism or a thin slice of animal or plant tissue, and then through glass lenses. The lenses bend the light in such a way that the image of the specimen is magnified as it is projected into your eye or a camera.

Magnification is the increase in the apparent size of an object. **Figure 3.1A** shows a single-celled protist called *Paramecium*. The notation "LM230×" printed along the right edge of this **micrograph** tells you that the photograph was taken through a light microscope and that this image is 230 times the actual size of the organism.

The actual size of this *Paramecium* is about 0.33 millimeter (mm) in length. **Figure 3.1B** shows the size range of cells compared with objects both larger and smaller. The most common units of length that biologists use are listed at the bottom of the figure. Notice that the scale along the left side of the figure is logarithmic to accommodate the range of sizes shown. Starting at the top of the scale with 10 meters (m) and going down, each reference measurement marks a 10-fold decrease in length. Most cells are between 1 and 100 micrometers (μm) in diameter (yellow region of the figure) and are therefore visible only with a microscope. Certain bacteria are as small as 0.2 μm in diameter and can barely be seen with a light microscope, whereas bird eggs are large enough to be seen with the unaided eye. A single nerve cell running from the base of your spinal cord to your big toe may be 1 m in length, although it is so thin you would still need a microscope to see it.



▲ **Figure 3.1A** Light micrograph of a protist, *Paramecium*



1 meter (m) = 10^0 meter (m) = 39.4 inches
1 centimeter (cm) = 10^{-2} m = 0.4 inch
1 millimeter (mm) = 10^{-3} m
1 micrometer (μm) = 10^{-3} mm = 10^{-6} m
1 nanometer (nm) = 10^{-3} μm = 10^{-9} m

▲ **Figure 3.1B** The size range of cells and related objects

Light microscopes can effectively magnify objects about 1,000 times. Greater magnification does not show more details clearly; indeed, the image becomes blurry. Thus, another important factor in microscopy is *resolution*, a measure of the clarity of an image. Resolution is the ability of an optical instrument to show two nearby objects as separate.

For example, what looks to your unaided eye like a single star in the sky may be resolved as twin stars with a telescope. Just as the resolution of the human eye is limited, the light microscope cannot resolve detail finer than about 0.2 μm, about the size of the smallest bacterium. No matter how many times its image of such a bacterium is magnified, the light microscope cannot show the details of this small cell's structure.

From the time that Hooke discovered cells in 1665 until the middle of the 20th century, biologists had only light microscopes for viewing cells. With these microscopes and various staining techniques to increase contrast and highlight parts of the sample, these early biologists discovered a great deal—microorganisms, animal and plant cells, and even some of the structures within cells. By the mid-1800s, these discoveries led to the **cell theory**, which states that all living things are composed of cells and that all cells come from other cells.

Our knowledge of cell structure took a giant leap forward as biologists began using the electron microscope in the 1950s. Instead of using light, an **electron microscope (EM)** focuses a beam of electrons through a specimen or onto its surface. Electron microscopes can distinguish biological structures as small as about 2 nanometers (nm), a 100-fold improvement over the light microscope. This high resolution has enabled biologists to explore cell ultrastructure, the complex internal anatomy of a cell.

? Which type of microscope would you use to study (a) the changes in shape of a living human white blood cell; (b) the finest details of surface texture of a human hair; (c) the detailed structure of an organelle in a liver cell?

(a) Light microscope; (b) scanning electron microscope; (c) transmission electron microscope.

3.2 Prokaryotic cells are structurally simpler than eukaryotic cells

Two kinds of cells, which differ in size and structure, have developed over time. Bacteria and archaea consist of **prokaryotic cells**, whereas all other forms of life (protists, fungi, plants, and animals) are composed of **eukaryotic cells**. Eukaryotic cells are distinguished by having a membrane-enclosed nucleus, which houses most of their DNA. The word *eukaryote* means "true nucleus" (from the Greek *eu*, true, and *karyon*, kernel, referring to the nucleus). The word *prokaryote* means "before nucleus" (from the Greek *pro*, before), reflecting the fact that prokaryotic cells developed before eukaryotic cells. They are also, as you shall see, structurally much simpler than eukaryotic cells while sharing some common characteristics.

All cells have several basic features in common. In addition to being bounded by a plasma membrane, all cells have one or more **chromosomes** carrying genes made of DNA. And all cells contain **ribosomes**, tiny structures that make proteins according to instructions from the genes. The interior of both types of cell is called the **cytoplasm**. However, in eukaryotic cells, this term refers only to the region between the nucleus and the plasma membrane. The cytoplasm of a eukaryotic cell contains many membrane-enclosed organelles that perform specific functions.

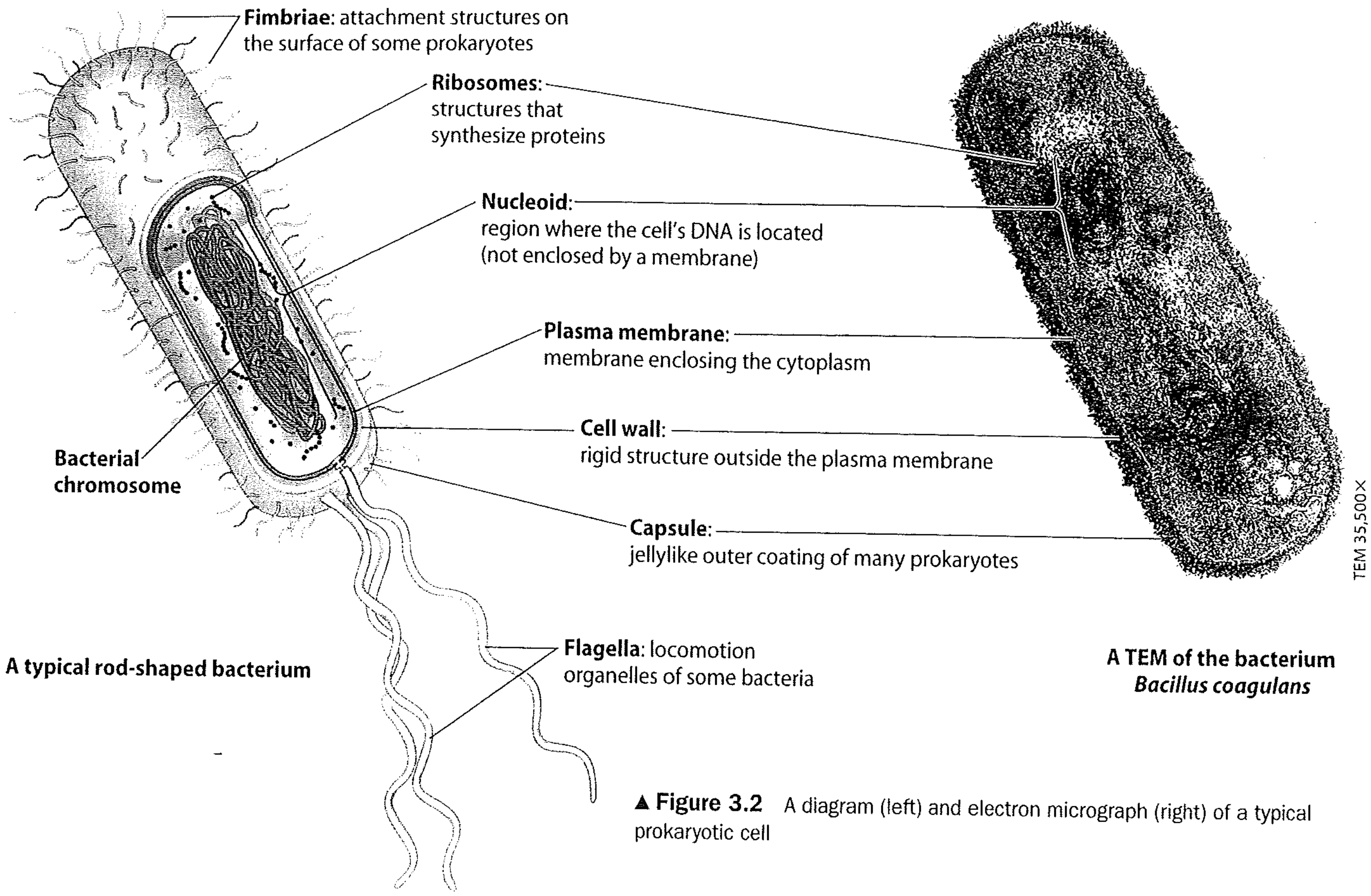
The cutaway diagram in **Figure 3.2** reveals the structure of a generalized prokaryotic cell. Notice that the DNA is coiled into a region called the **nucleoid** (nucleus-like), but in contrast to the nucleus of eukaryotic cells, no membrane surrounds the DNA. The ribosomes of prokaryotes (shown here in brown) are smaller and differ somewhat from those of eukaryotes. These molecular differences are the basis for the action of some antibiotics, such as tetracycline and streptomycin, which target prokaryotic ribosomes. Thus, protein synthesis can be blocked for the bacterium that's invaded you, but not for you, the eukaryote who is taking the drug.

Outside the plasma membrane (shown here in gray) of most prokaryotes is a fairly rigid, chemically complex cell wall (orange). The wall protects the cell and helps maintain its shape. Some antibiotics, such as penicillin, prevent the formation of these protective walls. Again, since your cells don't have such walls, these antibiotics can kill invading bacteria without harming your cells. Certain prokaryotes have a sticky outer coat called a capsule (yellow) around the cell wall, helping to glue the cells to surfaces, such as sticks and rocks in fast-flowing streams or tissues within the human body. In addition to capsules, some prokaryotes have surface projections. Short projections help attach prokaryotes to each other or their substrate. Longer projections called **flagella** (singular, *flagellum*) propel a prokaryotic cell through its liquid environment.

It takes an electron microscope to see the details of any cell, and this is especially true of prokaryotic cells (Figure 3.2, right side). Most prokaryotic cells are about one-tenth the size of a typical eukaryotic cell. Eukaryotic cells are the main focus of this chapter, so we turn to these next.

? List three features that are common to prokaryotic and eukaryotic cells. List three features that differ.

Both types of cells have plasma membranes, chromosomes containing DNA, and ribosomes. Prokaryotic cells are smaller, do not have a nucleus that houses their DNA or other membrane-enclosed organelles, and have smaller, somewhat different ribosomes.



▲ **Figure 3.2** A diagram (left) and electron micrograph (right) of a typical prokaryotic cell

3.3 Eukaryotic cells are partitioned into functional compartments

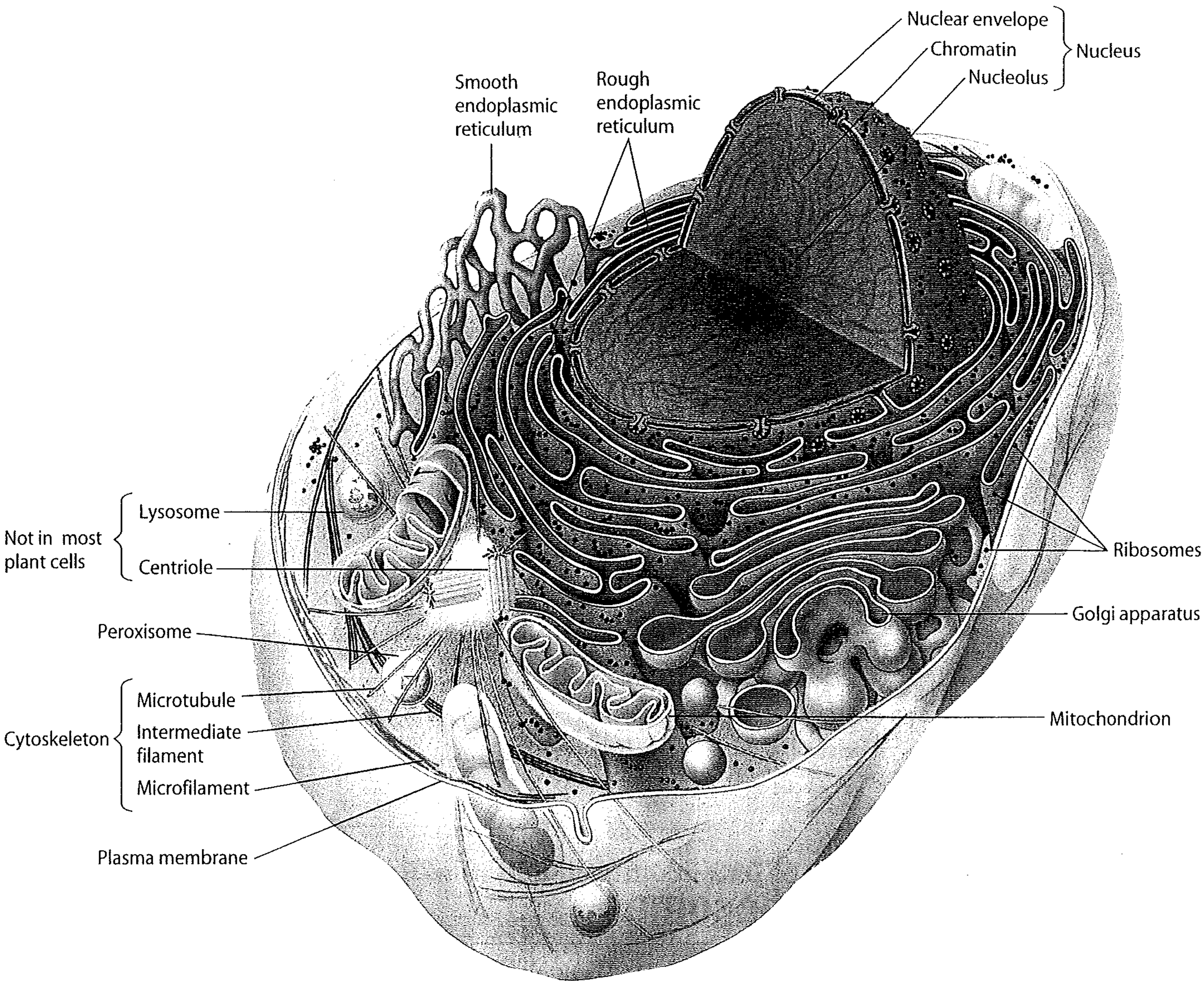
All eukaryotic cells—whether from animals, plants, protists, or fungi—are fundamentally similar to one another and profoundly different from prokaryotic cells. Let's look at an animal cell and a plant cell as representatives of the eukaryotes.

Figure 3.3A is a diagram of an idealized animal cell. No cell would look exactly like this. We color-code the various organelles and other structures in the diagrams for easier identification. And recall from the chapter introduction that in living cells many of these structures are moving and interacting.

The nucleus is the most obvious difference between a prokaryotic and eukaryotic cell. A eukaryotic cell also contains various other **organelles** ("little organs"), which perform specific functions in the cell. Just as the cell itself is wrapped in a membrane made of phospholipids and proteins that perform various functions, each organelle is bounded by a membrane with a lipid and protein composition that suits its function.

The organelles and other structures of eukaryotic cells can be organized into four basic functional groups as follows: (1) The nucleus and ribosomes carry out the genetic control of the cell. (2) Organelles involved in the manufacture, distribution, and breakdown of molecules include the endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and peroxisomes. (3) Mitochondria in all cells and chloroplasts in plant cells function in energy processing. (4) Structural support, movement, and communication between cells are the functions of the cytoskeleton, plasma membrane, and plant cell wall. These cellular components are identified in the figures on these two pages and will be examined in greater detail in the remaining modules of this chapter.

In essence, the internal membranes of a eukaryotic cell partition it into compartments. Many of the chemical activities of cells—activities known collectively as **cellular metabolism**—occur within organelles. In fact, many enzymatic proteins essential for metabolic processes are built into the membranes of organelles. The fluid-filled spaces within organelles are important as sites where specific chemical conditions are maintained. These conditions vary from one organelle to another and favor the metabolic processes occurring in each kind of organelle. For example, while a part of the endoplasmic reticulum is engaged in making steroid hormones, neighboring peroxisomes may be detoxifying harmful compounds and making hydrogen peroxide (H_2O_2) as a poisonous by-product of their activities.



▲ **Figure 3.3A** An animal cell

But because the H_2O_2 is confined within peroxisomes, where it is quickly converted to H_2O by resident enzymes, the rest of the cell is protected from destruction.

Almost all of the organelles and other structures of animal cells are also present in plant cells. As you can see in Figure 3.3A, however, there are a few exceptions: Lysosomes and centrioles are not found in plant cells. Also, although some animal cells have flagella or cilia (not shown in Figure 3.3A), among plants, only the sperm cells of a few species have flagella. (The flagella of prokaryotic cells differ in both structure and function from eukaryotic flagella.)

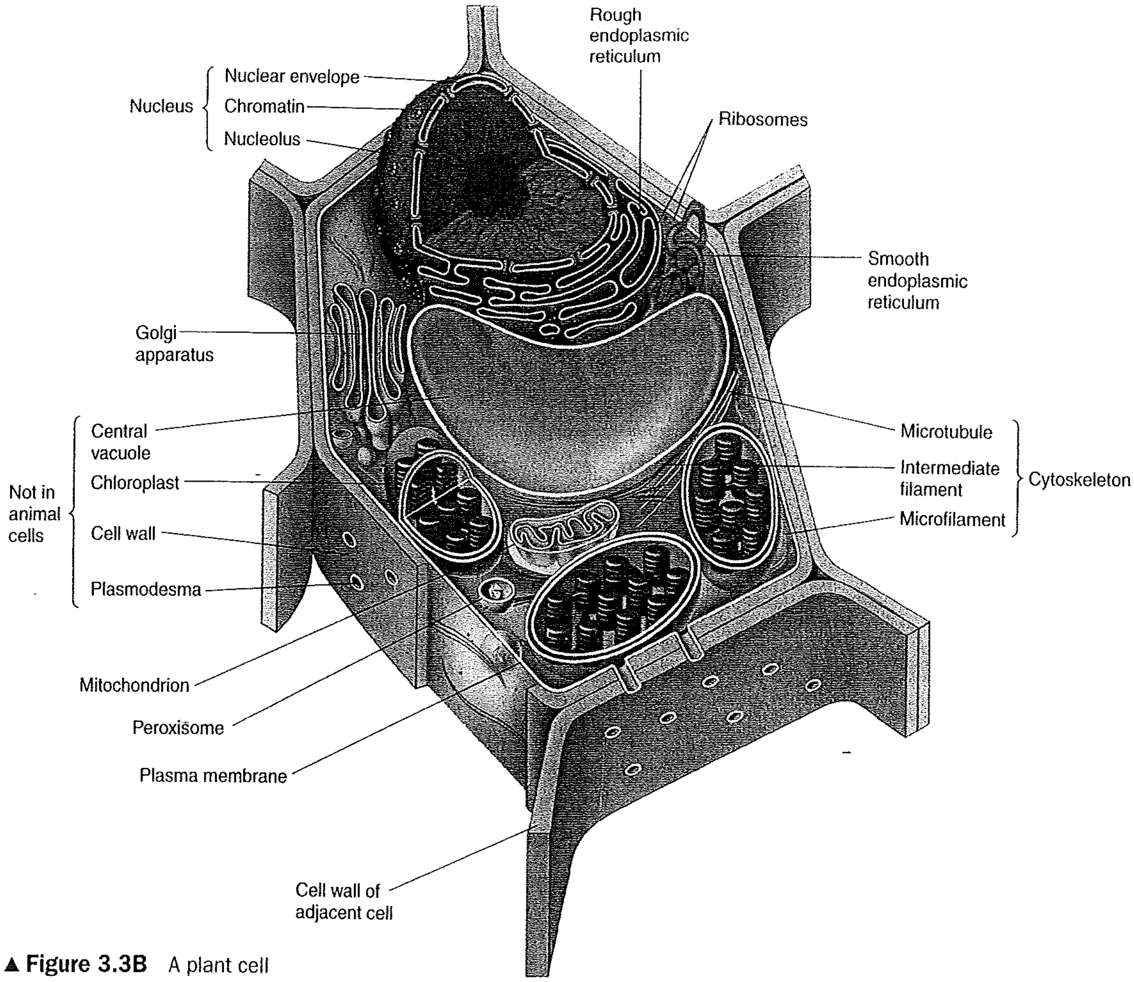
A plant cell **(Figure 3.3B)** also has some structures that an animal cell lacks. For example, a plant cell has a rigid, rather thick cell wall (as do the cells of fungi and many protists). Cell walls protect cells and help maintain their shape. Chemically different from prokaryotic cell walls, plant cell walls contain the polysaccharide cellulose. Plasmodesmata (singular, plasmodesma) are cytoplasmic channels through cell walls that connect adjacent cells. An important organelle found in plant cells is the chloroplast, where photosynthesis occurs. (Chloroplasts are also found in algae and some other protists.) Unique to plant cells is a large central vacuole, a compartment that stores water and a variety of chemicals.

Although we have emphasized organelles, eukaryotic cells contain nonmembranous structures as well. The cytoskeleton is composed of different types of protein fibers that extend throughout the cell. These networks provide for support and movement. As you can see by the many brown dots in both figures, ribosomes occur throughout the cytoplasm, as they do in prokaryotic cells. In addition, eukaryotic cells have many ribosomes attached to parts of the endoplasmic reticulum (making it appear "rough") and to the outer membrane of the nucleus.

Let's begin our in-depth tour of the eukaryotic cell, starting with the nucleus.

? Which of the following cellular structures differs from the others in the list: mitochondrion, chloroplast, ribosome, lysosome, vacuole? How does it differ?

Ribosome, because it is the only structure in the list that is not bounded by a membrane.



▲ **Figure 3.3B** A plant cell

The Nucleus and Ribosomes

3.4 The nucleus is the cell's genetic control center

The **nucleus** contains most of the cell's DNA—its master plans—and controls the cell's activities by directing protein synthesis. The DNA is associated with many proteins in the structures called chromosomes. The proteins help organize and coil the long DNA molecule. Indeed, the DNA of the 46 chromosomes in one of your cells laid end to end would stretch to a length of over 2 m, but it must coil up to fit into a nucleus only 5 μm in diameter. When a cell is not dividing, this complex of proteins and DNA, called **chromatin**, appears as a diffuse mass, as shown in the TEM (left) and diagram (right) of a nucleus in **Figure 3.4.**

As a cell prepares to divide, the DNA is copied so that each daughter cell can later receive an identical set of genetic instructions. Just prior to cell division, the thin chromatin fibers coil up further, becoming thick enough to be visible with a light microscope as the familiar separate structures you would probably recognize as chromosomes.

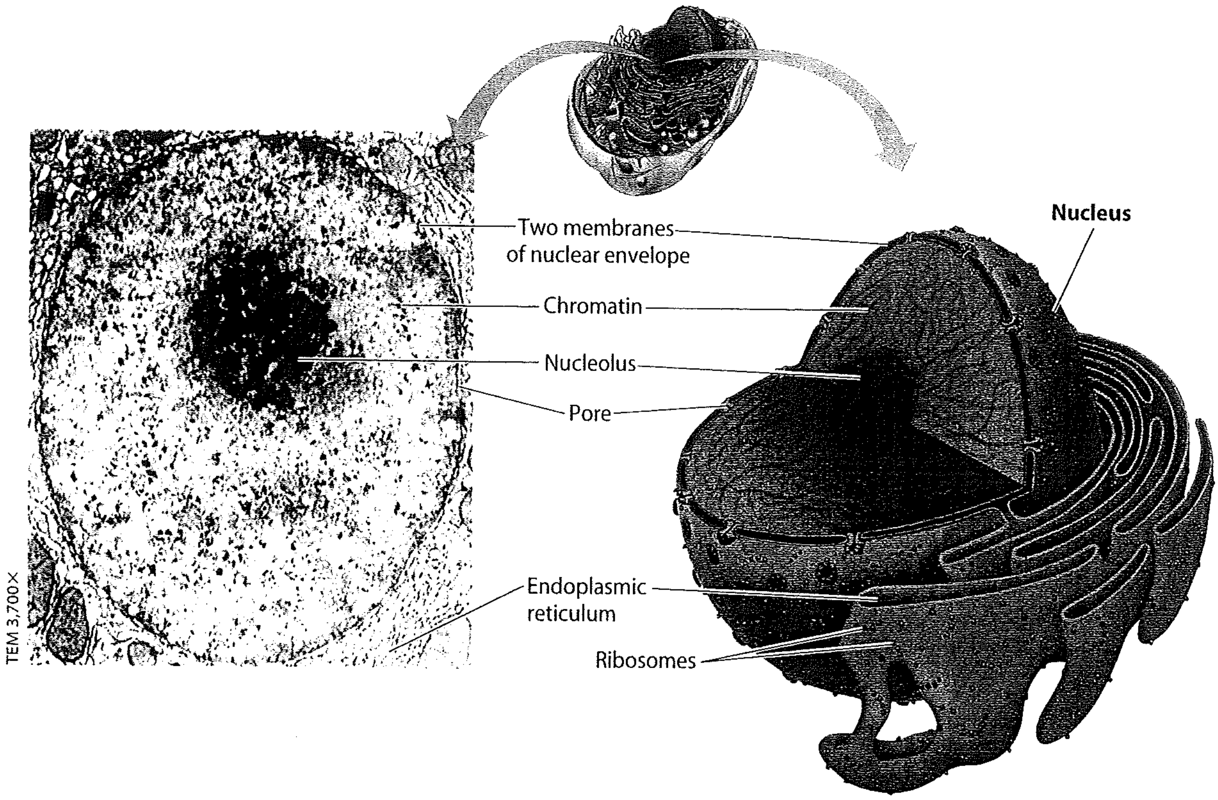
Enclosing the nucleus is a double membrane called the **nuclear envelope**. Each of the membranes is a separate phospholipid bilayer with associated proteins. Similar in function to the plasma membrane, the nuclear envelope controls the flow of materials into and out of the nucleus. As you can see in the diagram in Figure 3.4, the nuclear envelope is perforated with protein-lined pores that regulate the movement of large molecules and also connects with the cell's network of membranes called the endoplasmic reticulum.

The **nucleolus**, a prominent structure in the nucleus, is the site where a special type of RNA called *ribosomal RNA* (rRNA) is synthesized according to instructions in the DNA. Proteins brought in through the nuclear pores from the cytoplasm are assembled with this rRNA to form the subunits of ribosomes. These subunits then exit through the pores to the cytoplasm, where they will join to form functional ribosomes.

The nucleus directs protein synthesis by making another type of RNA, *messenger RNA* (mRNA). Essentially, mRNA is a transcription of protein-synthesizing instructions written in a gene's DNA (see Figure 2.12). The mRNA moves through the pores in the nuclear envelope to the cytoplasm. There it is translated by ribosomes into the amino acid sequences of proteins. Let's look at ribosomes next.

? What are the main functions of the nucleus?

To house and copy DNA and pass it on to daughter cells in cell division; to build ribosomal subunits; to transcribe DNA instructions into RNA and thereby control the cell's functions.



▲ **Figure 3.4** Transmission electron micrograph (left) and diagram (right) of the nucleus

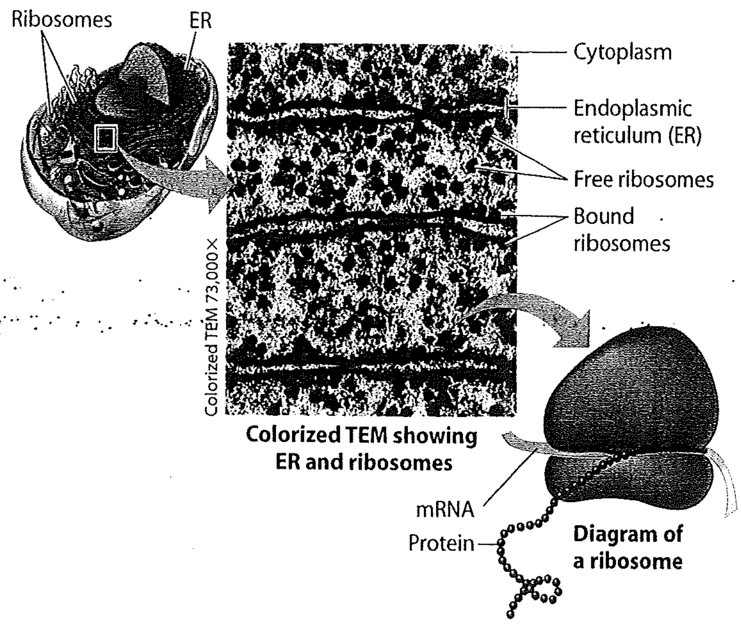
3.5 Ribosomes make proteins for use in the cell and for export

If the nucleus is the command center, then ribosomes are the machines on which those commands are carried out. Ribosomes are the cellular components that use instructions sent from the nucleus to carry out protein synthesis. Cells that make a lot of proteins have a large number of ribosomes. For example, a human pancreas cell producing digestive enzymes may contain a few million ribosomes. What other structure would you expect to be prominent in cells that are active in protein synthesis? As you just learned, nucleoli assemble the subunits of ribosomes out of ribosomal RNA and protein.

As shown in the colorized TEM in **Figure 3.5**, ribosomes are found in two locations in the cell. *Free ribosomes* are suspended in the fluid of the cytoplasm, while *bound ribosomes* are attached to the outside of the endoplasmic reticulum or nuclear envelope. Free and bound ribosomes are structurally identical, and ribosomes can alternate between the two locations.

Most of the proteins made on free ribosomes function within the cytoplasm; examples are enzymes that catalyze the first steps of sugar breakdown. In Module 3.6, you will see how bound ribosomes make proteins that will be inserted into membranes, packaged in certain organelles, or exported from the cell.

At the bottom right in Figure 3.5, you see how ribosomes interact with messenger RNA (carrying the instructions from a gene) to build a protein. The nucleotide sequence of an mRNA molecule is translated into the amino acid sequence of a polypeptide. Protein synthesis is explored in more detail in Chapter 9. Next let's look at more of the manufacturing equipment of the cell.



▲ **Figure 3.5** The locations and structure of ribosomes

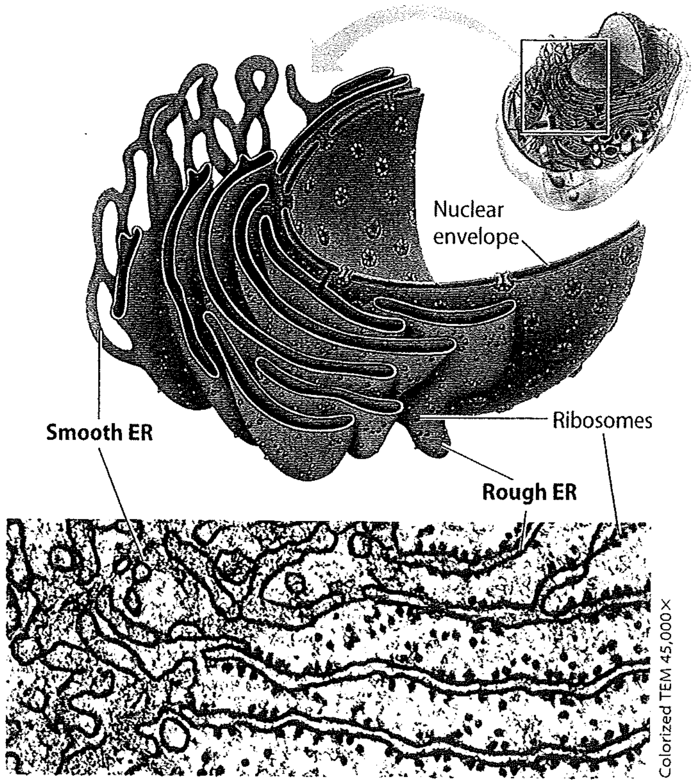
? What role do ribosomes play in carrying out the genetic instructions of a cell?

Ribosomes synthesize proteins according to the instructions carried by messenger RNA from the DNA in the nucleus.

The Endomembrane System

3.6 The endoplasmic reticulum is a biosynthetic factory

One of the major manufacturing sites in a cell is the endoplasmic reticulum. The diagram in **Figure 3.6A** shows a cutaway view of the interconnecting membranes of the smooth and rough ER. These two types of ER can be distinguished in the electron micrograph. **Smooth endoplasmic reticulum** is called *smooth* because it lacks attached ribosomes. **Rough endoplasmic reticulum** has ribosomes that stud the outer surface of the membrane; thus, it appears *rough* in the electron micrograph.

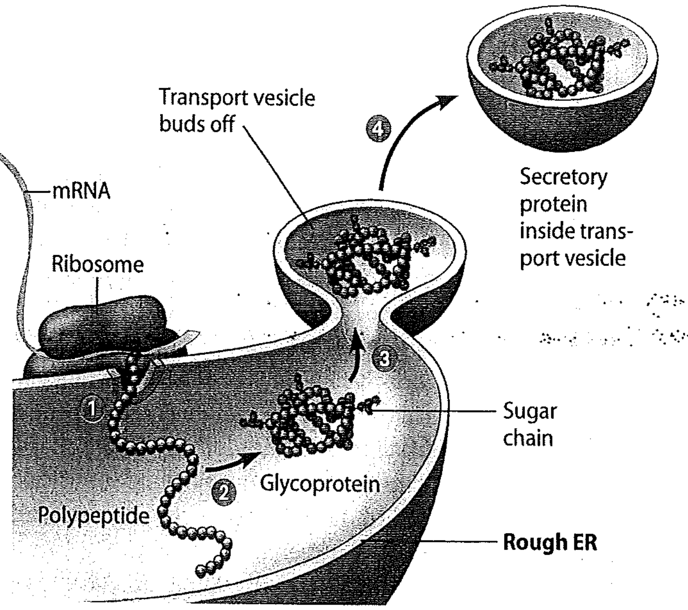


▲ **Figure 3.6A** Smooth and rough endoplasmic reticulum

Smooth ER The smooth ER of various cell types functions in a variety of metabolic processes. Enzymes of the smooth ER are important in the synthesis of lipids, including oils, phospholipids, and steroids. In vertebrates, for example, cells of the ovaries and testes synthesize the steroid sex hormones. These cells are rich in smooth ER, a structural feature that fits their function by providing ample machinery for steroid synthesis.

Our liver cells also have large amounts of smooth ER, with other important functions. Certain enzymes in the smooth ER of liver cells help process drugs and other potentially harmful substances. The sedative phenobarbital and other barbiturates are examples of drugs detoxified by these enzymes. As liver cells are exposed to such chemicals, the amount of smooth ER and its detoxifying enzymes increases, thereby increasing the rate of detoxification and thus the body's tolerance to the drugs. The result is a need for higher and higher doses of a drug to achieve a particular effect, such as sedation. Also, because detoxifying enzymes often cannot distinguish among related chemicals, the growth of smooth ER in response to one drug can increase tolerance to other drugs. Barbiturate abuse, for example, can decrease the effectiveness of certain antibiotics and other useful drugs.

Smooth ER has yet another function, the storage of calcium ions. In muscle cells, for example, a specialized smooth ER membrane pumps calcium ions into the interior of the ER. When a nerve signal stimulates a muscle cell, calcium ions rush from the smooth ER into the cytoplasmic fluid and trigger contraction of the cell.



▲ **Figure 3.6B** Synthesis and packaging of a secretory protein by the rough ER

Rough ER One of the functions of rough ER is to make more membrane. Phospholipids made by enzymes of the rough ER are inserted into the ER membrane. Thus, the ER membrane grows, and portions of it are transferred to other components of the endomembrane system as vesicles.

The bound ribosomes attached to rough ER produce proteins that will be inserted into the growing ER membrane, transported to other organelles, or secreted by the cell. An example of a secretory protein is insulin, a hormone secreted by specialized cells in the pancreas. Type 1 diabetes results when these cells are destroyed and a lack of insulin disrupts glucose metabolism in the body.

Figure 3.6B follows the synthesis, modification, and packaging of a secretory protein. 1 As the polypeptide is synthesized by a bound ribosome following the instructions of an mRNA, it is threaded into the cavity of the rough ER. As it enters, the new protein folds into its three-dimensional shape. 2 Short chains of sugars are often linked to the polypeptide, making the molecule a **glycoprotein** (*glyco* means "sugar"). 3 When the molecule is ready for export from the ER, it is packaged in a **transport vesicle**, a vesicle that moves from one part of the cell to another. 4 This vesicle buds off from the ER membrane.

The vesicle now carries the protein to the Golgi apparatus (described in the next module) for further processing. From there, a transport vesicle containing the finished molecule makes its way to the plasma membrane and releases its contents from the cell.

? Explain why we say that the endoplasmic reticulum is a biosynthetic factory.

The ER produces a huge variety of molecules, including phospholipids for cell membranes, steroid hormones, and proteins (synthesized by bound ribosomes) for membranes, other organelles, and secretion by the cell.

3.7 The Golgi apparatus finishes, sorts, and ships cell products

After leaving the ER, many transport vesicles travel to the **Golgi apparatus**. Using a light microscope and a staining technique he developed, Italian scientist Camillo Golgi discovered this membranous organelle in 1898. The electron microscope confirmed his discovery more than 50 years later, revealing a stack of flattened sacs, looking much like a pile of pita bread. A cell may contain many, even hundreds, of these stacks. The number of Golgi stacks correlates with how active the cell is in secreting proteins—a multistep process that, as we have just seen, is initiated in the rough ER.

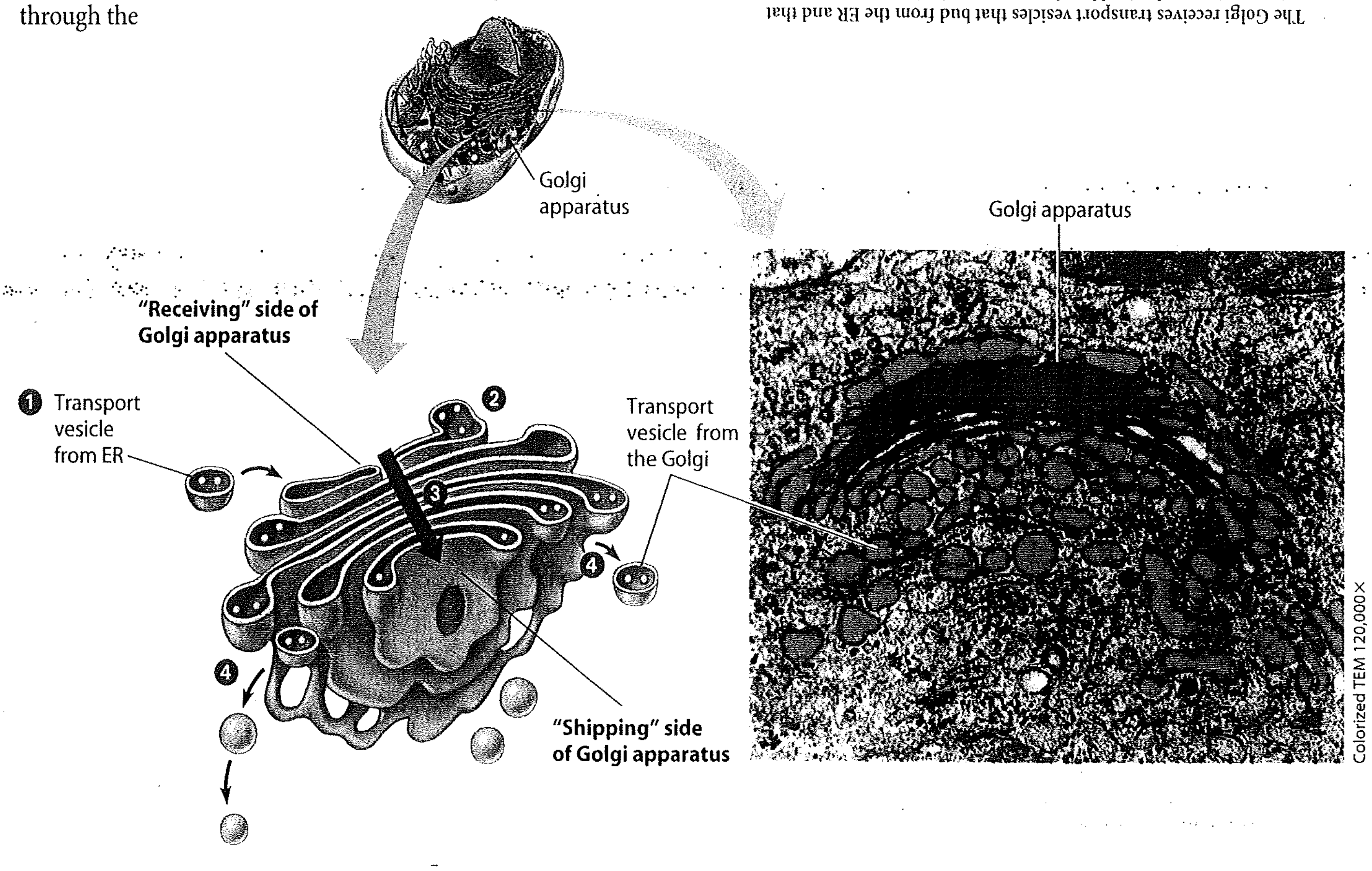
The Golgi apparatus serves as a molecular warehouse and finishing factory for products manufactured by the ER. You can follow this process in **Figure 3.7**. Note that the flattened Golgi sacs are not connected, as are ER sacs. ❶ One side of a Golgi stack serves as a receiving dock for transport vesicles produced by the ER. ❷ A vesicle fuses with a Golgi sac, adding its membrane and contents to the receiving side. ❸ Products of the ER are modified during their transit through the Golgi. ❹ The other side of the Golgi, the shipping side, gives rise to vesicles, which bud off and travel to other sites.

How might ER products be processed during their transit through the Golgi? Various Golgi enzymes modify the carbohydrate portions of the glycoproteins made in the ER, removing some sugars and substituting others. Molecular identification tags, such as phosphate groups, may be added that help the Golgi sort molecules into different batches for different destinations.

Until recently, the Golgi was viewed as a static structure, with products in various stages of processing moved from sac to sac by transport vesicles. Recent research has given rise to a new *maturation model* in which entire sacs "mature" as they move from the receiving to the shipping side, carrying and modifying their cargo as they go. The shipping side of the Golgi stack serves as a depot from which finished secretory products, packaged in transport vesicles, move to the plasma membrane for export from the cell. Alternatively, finished products may become part of the plasma membrane itself or part of another organelle, such as a lysosome, which we discuss next.

? What is the relationship of the Golgi apparatus to the ER in a protein-secreting cell?

The Golgi receives transport vesicles that bud from the ER and that contain proteins synthesized by ribosomes attached to the ER. The Golgi finishes processing the proteins and then dispatches transport vesicles that secrete the proteins to the outside of the cell.



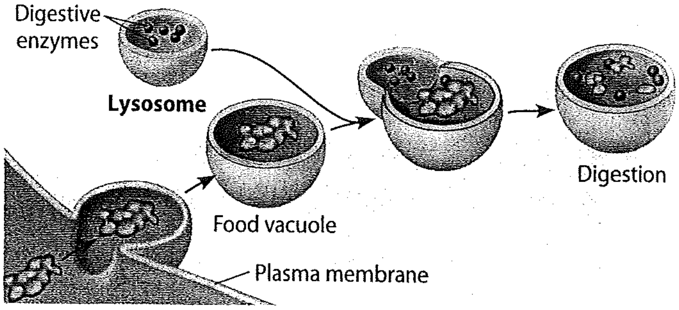
▲ **Figure 3.7** The Golgi apparatus

3.8 Lysosomes are digestive compartments within a cell

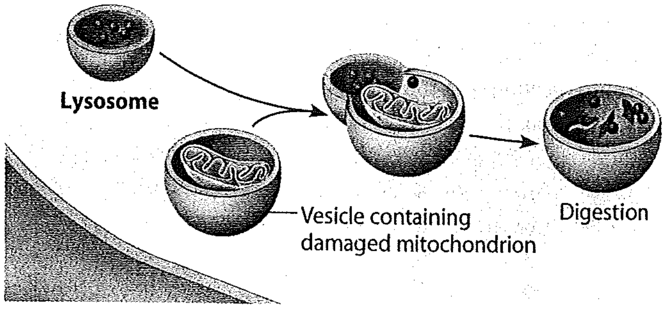
A **lysosome** is a membranous sac of digestive enzymes. The name *lysosome* is derived from two Greek words meaning "breakdown body." The enzymes and membranes of lysosomes are made by rough ER and processed in the Golgi apparatus. Illustrating a main theme of eukaryotic cell structure—compartmentalization—a lysosome provides an acidic environment for its enzymes, while safely isolating them from the rest of the cell.

Lysosomes have several types of digestive functions. Many protists engulf food particles into membranous sacs called food vacuoles. As **Figure 3.8A** shows, lysosomes fuse with food vacuoles and digest the food. The nutrients are then released into the cell fluid. Our white blood cells engulf and destroy bacteria using lysosomal enzymes. Lysosomes also serve as recycling centers for animal cells. Damaged organelles or small amounts of cell fluid become surrounded by a membrane. A lysosome fuses with such a vesicle **(Figure 3.8B)** and dismantles its contents, making organic molecules available for reuse. With the help of lysosomes, a cell continually renews itself.

The cells of people with inherited lysosomal storage diseases lack one or more lysosomal enzymes. The lysosomes become engorged with undigested material, eventually interfering with cellular function. In Tay-Sachs disease, for example, a lipid-digesting enzyme is missing, and brain cells become impaired by an accumulation of lipids. Lysosomal storage diseases are often fatal in early childhood.



▲ **Figure 3.8A** Lysosome fusing with a food vacuole and digesting food



▲ **Figure 3.8B** Lysosome fusing with a vesicle containing a damaged organelle and digesting and recycling its contents

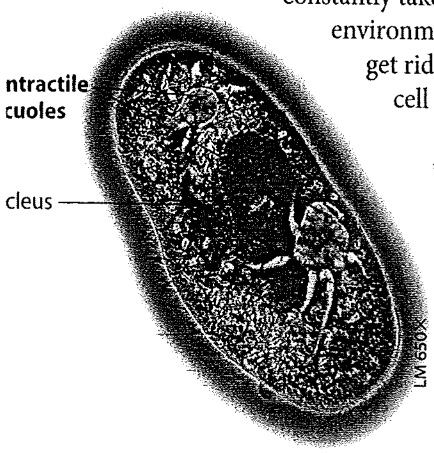
? **How is a lysosome like a recycling center?**

It breaks down damaged organelles and recycles their molecules.

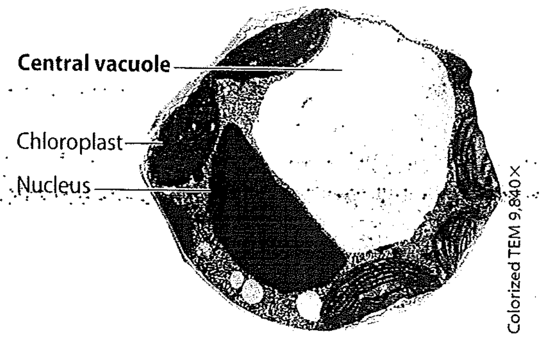
3.9 Vacuoles function in the general maintenance of the cell

Vacuoles are large vesicles that have a variety of functions. In Figure 3.8A, you saw how a food vacuole forms as a cell ingests food. **Figure 3.9A** shows two contractile vacuoles in the protist *Paramecium*, looking somewhat like wheel hubs with radiating spokes. The "spokes" collect water from the cell, and the hub expels it to the outside. Freshwater protists constantly take in water from their environment. Without a way to get rid of the excess water, the cell would swell and burst.

In plants, some vacuoles have a digestive function similar to that of lysosomes in animal cells. Vacuoles in flower petals contain pigments that attract pollinating insects. Vacuoles may also contain poisons or unpalatable compounds that protect the plant against herbivores; examples include nicotine, caffeine, and various chemicals we use as pharmaceutical drugs. **Figure 3.9B** shows a plant cell's large **central vacuole**, which helps the cell grow in size by absorbing water and enlarging. It also stockpiles vital chemicals and acts as a trash can, safely storing toxic waste products.



▲ **Figure 3.9A** Contractile vacuoles in *Paramecium*, a single-celled organism



▲ **Figure 3.9B** Central vacuole in a plant cell

? **Is a food vacuole part of the endomembrane system?**

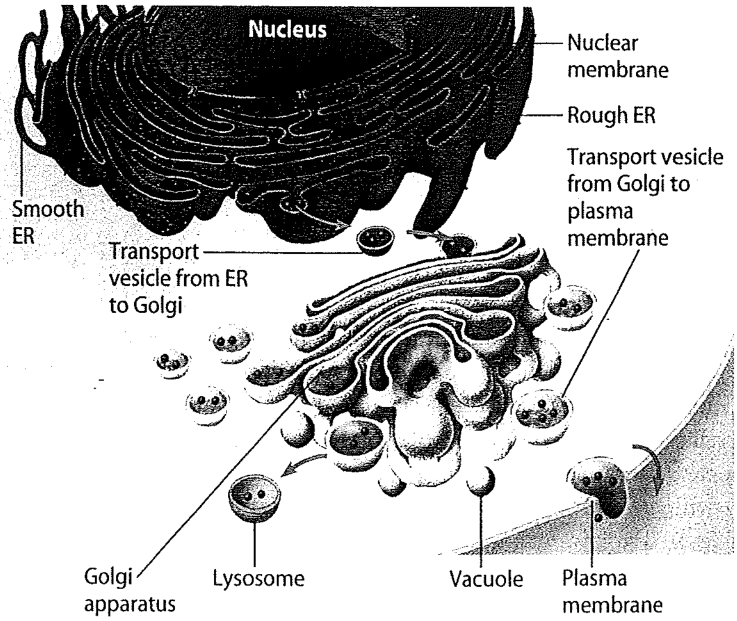
Yes; it forms by pinching in from the plasma membrane, which is part of the endomembrane system.

3.10 A review of the structures involved in manufacturing and breakdown

Figure 3.10 summarizes the relationships within the endomembrane system. You can see the direct *structural* connections between the nuclear envelope, rough ER, and smooth ER. The red arrows show the *functional* connections, as membranes and proteins produced by the ER travel in transport vesicles to the Golgi and on to other destinations. Some vesicles develop into lysosomes or vacuoles. Others transport products to the outside of the cell. When these vesicles fuse with the plasma membrane, their contents are secreted from the cell and their membrane is added to the plasma membrane.

Peroxisomes (see Figures 3.3A and B) are metabolic compartments that do not originate from the endomembrane system. In fact, how they are related to other organelles is still unknown. Some peroxisomes break down fatty acids to be used as cellular fuel. In your liver, peroxisomes detoxify harmful compounds, including alcohol. In these processes, enzymes transfer hydrogen from various compounds to oxygen, producing hydrogen peroxide (H_2O_2). Other enzymes in the peroxisome quickly convert this toxic product to water—another example of the importance of a cell's compartmental structure.

A cell requires a continuous supply of energy to perform the work of life. Next we consider two organelles that act as cellular power stations—mitochondria and chloroplasts.



▲ **Figure 3.10** Connections among the organelles of the endomembrane system

? **How do transport vesicles help tie together the endomembrane system?**

Transport vesicles move membranes and substances they enclose between components of the endomembrane system.

Energy-Converting Organelles

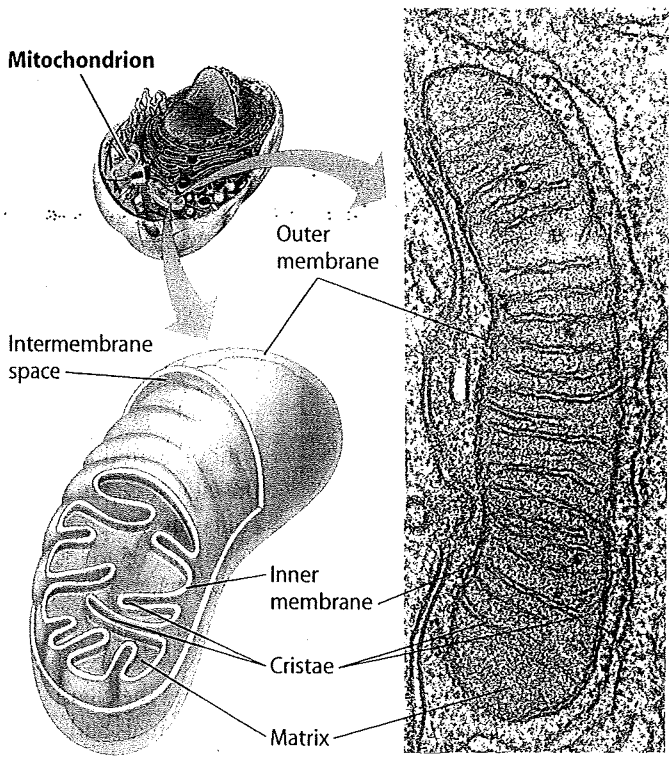
3.11 Mitochondria harvest chemical energy from food

Mitochondria (singular, *mitochondrion*) are organelles that carry out cellular respiration in nearly all eukaryotic cells, converting the chemical energy of foods such as sugars to the chemical energy of the molecule called ATP (adenosine triphosphate). ATP is the main energy source for cellular work.

As you have come to expect, a mitochondrion's structure suits its function. It is enclosed by two membranes, each a phospholipid bilayer with a unique collection of embedded proteins (**Figure 3.11**). The mitochondrion has two internal compartments. The first is the intermembrane space, the narrow region between the inner and outer membranes. The inner membrane encloses the second compartment, the **mitochondrial matrix**, which contains mitochondrial DNA and ribosomes, as well as many enzymes that catalyze some of the reactions of cellular respiration. The inner membrane is highly folded and contains many embedded protein molecules that function in ATP synthesis. The folds, called **cristae**, increase the membrane's surface area, enhancing the mitochondrion's ability to produce ATP.

? **What is cellular respiration?**

A process that converts the chemical energy of sugars and other food molecules to the chemical energy of ATP.

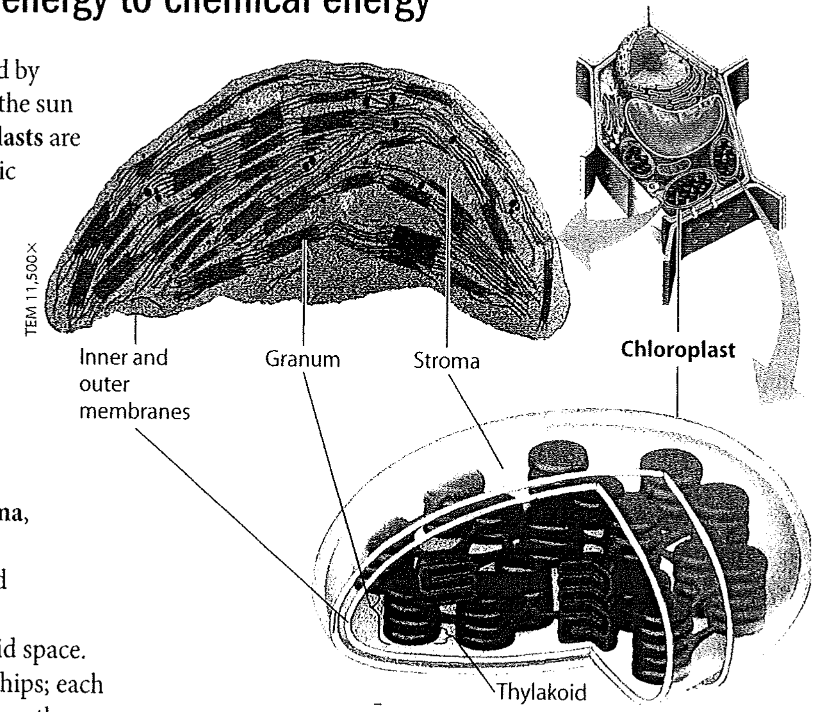


▲ **Figure 3.11** The mitochondrion

3.12 Chloroplasts convert solar energy to chemical energy

Most of the living world runs on the energy provided by photosynthesis, the conversion of light energy from the sun to the chemical energy of sugar molecules. **Chloroplasts** are the photosynthesizing organelles of all photosynthetic eukaryotes. The chloroplast's solar power system is much more efficient than anything yet produced by human ingenuity.

Befitting an organelle that carries out complex, multistep processes, internal membranes partition the chloroplast into compartments (**Figure 3.12**). The chloroplast is enclosed by an inner and outer membrane separated by a thin intermembrane space. The compartment inside the inner membrane holds a thick fluid called **stroma**, which contains chloroplast DNA and ribosomes as well as many enzymes. A network of interconnected sacs called **thylakoids** is inside the chloroplast. The compartment inside these sacs is called the thylakoid space. In some regions, thylakoids are stacked like poker chips; each stack is called a **granum** (plural, *grana*). The grana are the chloroplast's solar power packs—the sites where the green chlorophyll molecules embedded in thylakoid membranes trap solar energy.



▲ **Figure 3.12** The chloroplast

? **Which membrane in a chloroplast appears to be the most extensive? Why might this be so?**

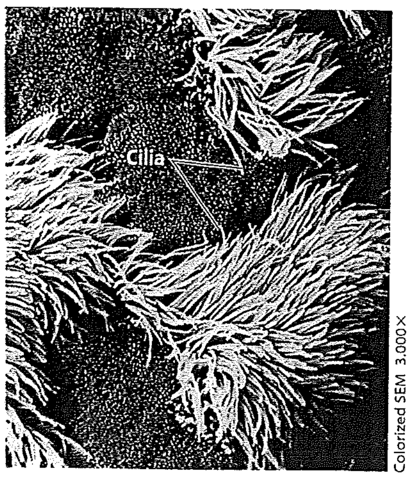
The thylakoid membranes are most extensive, providing a large area of membrane that contains chlorophyll for photosynthesis.

The Cytoskeleton and Cell Surfaces

3.13 Cilia and flagella

The role of the cytoskeleton in movement is clearly seen in the motile appendages that protrude from certain cells. The short, numerous appendages that propel protists such as *Paramecium* (see Figure 3.1C) are called **cilia** (singular, *cilium*). Other protists may move using flagella, which are longer than cilia and usually limited to one or a few per cell.

Some cells of multicellular organisms also have cilia or flagella. For example, **Figure 3.13A** shows cilia on cells lining the human windpipe. In this case, the cilia sweep mucus containing trapped debris out of your lungs. (This cleaning function is impaired by cigarette smoke, which paralyzes the cilia.) Most animals and some plants have flagellated sperm.



▲ **Figure 3.13A** Cilia on cells lining the respiratory tract

A flagellum, shown in **Figure 3.13B**, propels the cell by an undulating whiplike motion. In contrast, cilia work more like the coordinated oars of a rowing team.

Though different in length and beating pattern, cilia and flagella have a common structure and mechanism of movement (**Figure 3.13C**). Both are composed of microtubules wrapped in an extension of the plasma membrane. In nearly all eukaryotic cilia and flagella, a ring of nine microtubule doublets surrounds a central pair of microtubules. This arrangement is called the 9 + 2 pattern. The microtubule assembly extends into an anchoring structure called a basal body (not shown in the figure), which consists of a ring of nine microtubule triplets. Basal bodies are very similar in structure to centrioles, which are found in the microtubule-organizing center of animal cells.

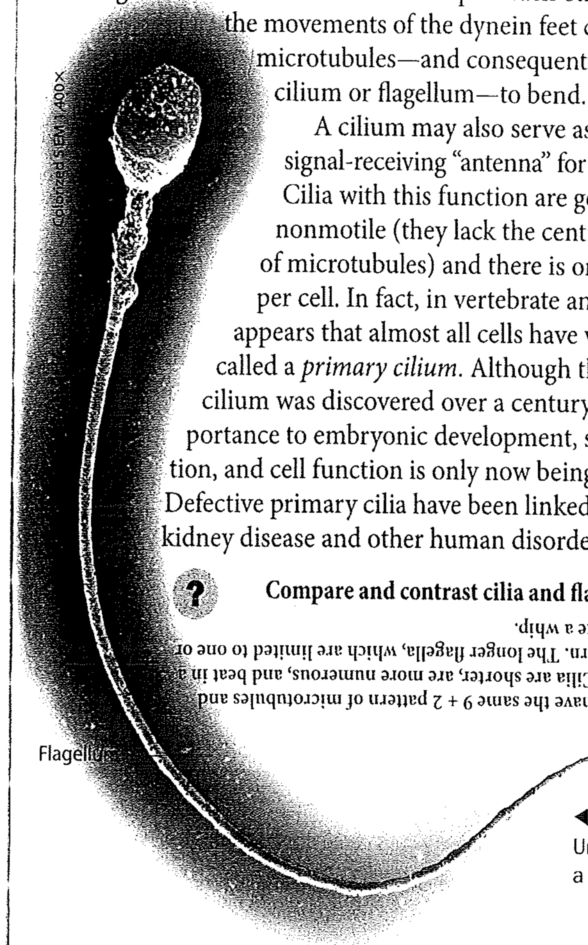
How does this microtubule assembly produce the bending movement of cilia and flagella? Bending involves large motor proteins called dyneins (red in the figure) that are attached along each outer microtubule doublet. A dynein protein has two "feet" that "walk" along an adjacent doublet, one foot maintaining contact while the other releases and reattaches one step farther along its neighboring microtubule. The outer doublets and two central microtubules are held together by

flexible cross-linking proteins and radial spokes (purple in the diagram). If the doublets were not held in place, the walking action would make them slide past each other. Instead, the movements of the dynein feet cause the microtubules—and consequently the cilium or flagellum—to bend.

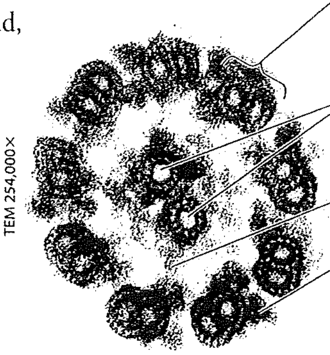
A cilium may also serve as a signal-receiving "antenna" for the cell. Cilia with this function are generally nonmotile (they lack the central pair of microtubules) and there is only one per cell. In fact, in vertebrate animals, it appears that almost all cells have what is called a *primary cilium.* Although the primary cilium was discovered over a century ago, its importance to embryonic development, sensory reception, and cell function is only now being recognized. Defective primary cilia have been linked to polycystic kidney disease and other human disorders.

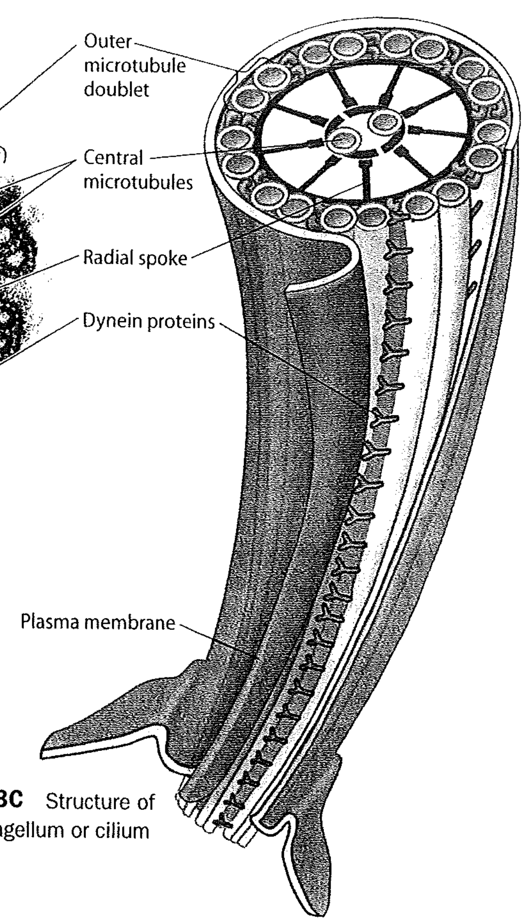
? Compare and contrast cilia and flagella.

Both cilia and flagella have the same 9 + 2 pattern of microtubules and mechanisms for bending. Cilia are shorter, are more numerous, and beat in a coordinated oar-like pattern. The longer flagella, which are limited to one or a few per cell, undulate like a whip.



◀ **Figure 3.13B** Undulating flagellum on a human sperm cell





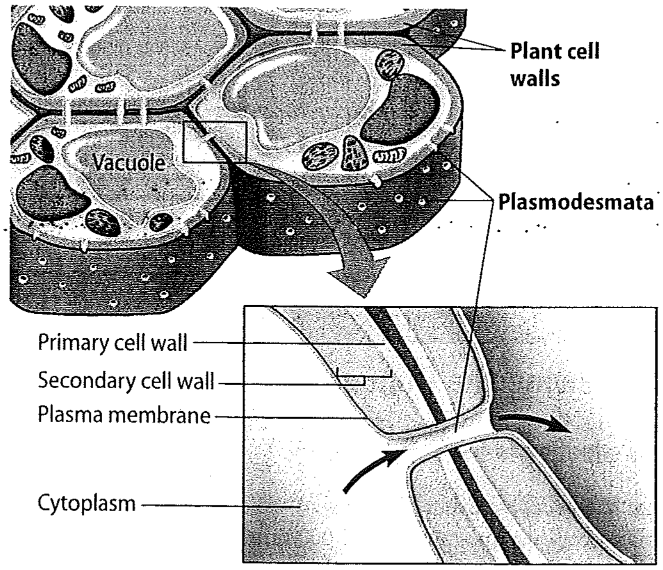
▲ **Figure 3.13C** Structure of a eukaryotic flagellum or cilium

3.14 Cell walls enclose and support plant cells

The **cell wall** is one feature that distinguishes plant cells from animal cells. This rigid extracellular structure not only protects the cells but provides the skeletal support that keeps plants upright on land. Plant cell walls consist of fibers of cellulose embedded in a matrix of other polysaccharides and proteins. This fibers-in-a-matrix construction resembles that of fiberglass, a manufactured product also noted for its strength.

Figure 3.14 shows the layered structure of plant cell walls. Cells initially lay down a relatively thin and flexible primary wall, which allows the growing cell to continue to enlarge. Some cells then add a secondary wall deposited in laminated layers. Wood consists mainly of secondary walls, which are strengthened with rigid molecules called lignin. Between adjacent cells is a layer of sticky polysaccharides called pectins (shown here in dark brown), which glue the cells together. (Pectin is used to thicken jams and jellies.)

Despite their thickness, plant cell walls do not totally isolate the cells from each other. To function in a coordinated way as part of a tissue, the cells must have cell junctions, structures that connect them to one another. Figure 3.14 shows the numerous channels between adjacent plant cells, called **plasmodesmata** (singular, *plasmodesma*). Notice that the plasma membrane and the cytoplasm of the cells extend through the plasmodesmata, so that water and other small molecules can readily pass from cell to cell. Through plasmodesmata, the cells of a plant tissue share water, nourishment, and chemical messages.



▲ **Figure 3.14** Plant cell walls and plasmodesmata

? Which animal cell junction is analogous to a plasmodesma?

A gap junction.

3.15 Review: Eukaryotic cell structures can be grouped on the basis of four main functions

Congratulations, you have completed the grand tour of the cell. In the process, you have been introduced to many important cell structures. To provide a framework for this information and reinforce the theme that structure is correlated with function, we have grouped the eukaryotic cell structures into four categories by general function, as reviewed in **Table 3.15**.

? How do mitochondria, smooth ER, and the cytoskeleton all contribute to the contraction of a muscle cell?

Mitochondria supply energy in the form of ATP. The smooth ER helps regulate contraction by the uptake and release of calcium ions. Microfilaments function in the actual contractile apparatus.

TABLE 3.15 | EUKARYOTIC CELL STRUCTURES AND FUNCTIONS

1. Genetic Control	
Nucleus	DNA replication, RNA synthesis; assembly of ribosomal subunits (in nucleoli)
Ribosomes	Polypeptide (protein) synthesis
2. Manufacturing, Distribution, and Breakdown	
Rough ER	Synthesis of membrane lipids and proteins, secretory proteins, and hydrolytic enzymes; formation of transport vesicles
Smooth ER	Lipid synthesis; detoxification in liver cells; calcium ion storage
Golgi apparatus	Modification and sorting of macromolecules; formation of lysosomes and transport vesicles
Lysosomes (in animal cells and some protists)	Digestion of ingested food, bacteria, and a cell's damaged organelles and macromolecules for recycling
Vacuoles	Digestion (food vacuole); storage of chemicals and cell enlargement (central vacuole); water balance (contractile vacuole)
Peroxisomes (not part of endomembrane system)	Diverse metabolic processes, with breakdown of toxic hydrogen peroxide by-product
3. Energy Processing	
Mitochondria	Conversion of chemical energy in food to chemical energy of ATP
Chloroplasts (in plants and some protists)	Conversion of light energy to chemical energy of sugars
4. Structural Support, Movement, and Communication Between Cells	
Cytoskeleton (microfilaments, intermediate filaments, and microtubules)	Maintenance of cell shape; anchorage for organelles; movement of organelles within cells; cell movement (crawling, muscle contraction, bending of cilia and flagella)
Extracellular matrix (in animals)	Support; regulation of cellular activities
Cell junctions	Communication between cells; binding of cells in tissues
Cell walls (in plants, fungi, and some protists)	Support and protection; binding of cells in tissues

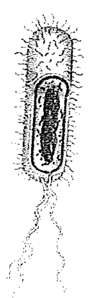
CHAPTER 3 REVIEW

Reviewing the Concepts

Introduction to the Cell (3.1–3.3)

3.1 Microscopes reveal the world of the cell. The light microscope can magnify up to 1,000 times. The greater magnification and resolution of the scanning and transmission electron microscopes reveal the ultrastructure of cells.

3.2 Prokaryotic cells are structurally simpler than eukaryotic cells. All cells have a plasma membrane, DNA, ribosomes, and cytoplasm. Prokaryotic cells are smaller than eukaryotic cells and lack a membrane-enclosed nucleus.



3.3 Eukaryotic cells are partitioned into functional compartments. Membranes form the boundaries of organelles, compartmentalizing a cell's activities.

The Nucleus and Ribosomes (3.4–3.5)

3.4 The nucleus is the cell's genetic control center. The nucleus houses the cell's DNA and directs protein synthesis by making messenger RNA. The nucleolus makes the subunits of ribosomes.

3.5 Ribosomes make proteins for use in the cell and for export. Composed of ribosomal RNA and proteins, ribosomes synthesize proteins according to directions from DNA.

The Endomembrane System (3.6–3.10)

3.6 The endoplasmic reticulum is a biosynthetic factory. The ER is a membranous network of tubes and sacs. Smooth ER synthesizes

lipids and processes toxins. Rough ER manufactures membranes, and ribosomes on its surface produce membrane and secretory proteins.

3.7 The Golgi apparatus finishes, sorts, and ships cell products. The Golgi apparatus consists of stacks of sacs that modify ER products and then ship them to other organelles or to the cell surface.

3.8 Lysosomes are digestive compartments within a cell. Lysosomes house enzymes that function in digestion and recycling within the cell.

3.9 Vacuoles function in the general maintenance of the cell. Some protists have contractile vacuoles. Plant cells contain a large central vacuole that stores molecules and wastes and facilitates growth.

3.10 A review of the structures involved in manufacturing and breakdown. The organelles of the endomembrane system are interconnected structurally and functionally.

Energy-Converting Organelles (3.11–3.12)

3.11 Mitochondria harvest chemical energy from food.

3.12 Chloroplasts convert solar energy to chemical energy.

The Cytoskeleton and Cell Surfaces (3.13–3.15)

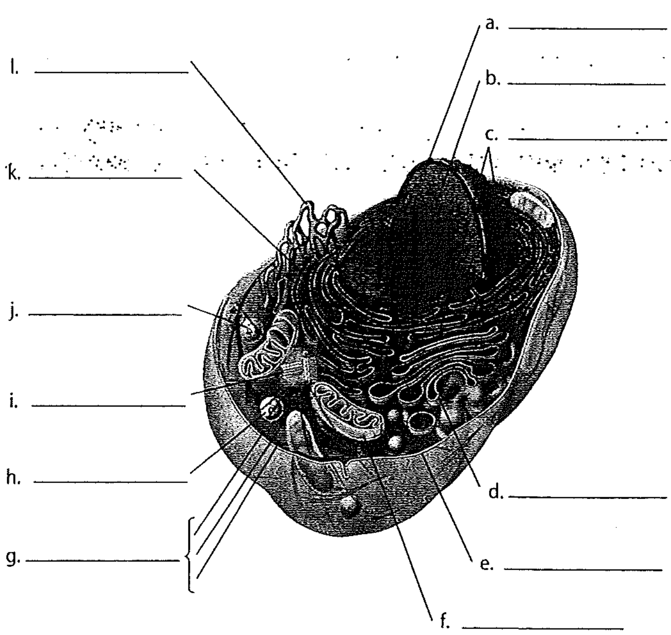
3.13 Cilia and flagella move when microtubules bend. Eukaryotic cilia and flagella are locomotor appendages made of microtubules in a 9 + 2 arrangement.

3.14 Cell walls enclose and support plant cells. Plant cell walls are made largely of cellulose. Plasmodesmata are connecting channels between cells.

3.15 Review: Eukaryotic cell structures can be grouped on the basis of four main functions. These functions are (1) genetic control; (2) manufacturing, distribution, and breakdown; (3) energy processing; and (4) structural support, movement, and communication between cells.

Connecting the Concepts

1. Label the structures in this diagram of an animal cell. Review the functions of each of these organelles.



2. List some structures found in animal cells but not in plant cells.
3. List some structures found in plant cells but not in animal cells.

Testing Your Knowledge

Multiple Choice

4. Which of the following clues would tell you whether a cell is prokaryotic or eukaryotic?
   a. the presence or absence of a rigid cell wall
   b. whether or not the cell is partitioned by internal membranes
   c. the presence or absence of ribosomes
   d. whether or not the cell carries out cellular metabolism
   e. whether or not the cell contains DNA
5. Which statement correctly describes bound ribosomes?
   a. Bound ribosomes are enclosed in a membrane.
   b. Bound and free ribosomes are structurally different.
   c. Bound ribosomes are most commonly found on the surface of the plasma membrane.
   d. Bound ribosomes generally synthesize membrane proteins and secretory proteins.
   e. Bound ribosomes produce the subunits of microtubules, microfilaments, and intermediate filaments.

Choose from the following cells for questions 6–10:
   a. muscle cell in thigh of long-distance runner
   b. pancreatic cell that secretes digestive enzymes
   c. ovarian cell that produces the steroid hormone estrogen
   d. cell in tissue layer lining digestive tract
   e. white blood cell that engulfs bacteria

6. In which cell would you find the most lysosomes?
7. In which cell would you find the most mitochondria?
8. In which cell would you find the most smooth ER?
9. In which cell would you find the most rough ER?
10. In which cell would you find the most tight junctions?
11. A type of cell called a lymphocyte makes proteins that are exported from the cell. Which of the following traces the path of a protein from the site where its polypeptides are made to its export?
    a. chloroplast . . . Golgi . . . lysosomes . . . plasma membrane
    b. Golgi . . . rough ER . . . smooth ER . . . transport vesicle
    c. rough ER . . . Golgi . . . transport vesicle . . . plasma membrane
    d. smooth ER . . . Golgi . . . lysosome . . . plasma membrane
    e. nucleus . . . rough ER . . . Golgi . . . plasma membrane
12. Which of the following structures is *not* directly involved in cell support or movement?
    a. microfilament
    b. flagellum
    c. microtubule
    d. gap junction
    e. cell wall

Describing, Comparing, and Explaining

13. What four cellular components are shared by prokaryotic and eukaryotic cells?
14. Briefly describe the three kinds of junctions that can connect animal cells, and compare their functions.
15. What general function do the chloroplast and mitochondrion have in common? How are their functions different?
16. In what ways do the internal membranes of a eukaryotic cell contribute to the functioning of the cell?
17. Describe two different ways in which the motion of cilia can function in organisms.

18. Explain how a protein inside the ER can be exported from the cell without ever crossing a membrane.
19. Is this statement true or false? "Animal cells have mitochondria; plant cells have chloroplasts." Explain your answer.
20. Describe the structure of the plasma membrane of an animal cell. What would be found directly inside and outside the membrane?

Applying the Concepts

21. Cilia are found on cells in almost every organ of the human body, and the malfunction of cilia is involved in several human disorders. During embryological development, for example, cilia generate a leftward flow of fluid that initiates the left-right organization of the body organs. Some individuals with primary ciliary dyskinesia exhibit *situs inversus*, in which internal organs such as the heart are on the wrong side of the body. Explain why this reversed arrangement may be a symptom of PCD.
22. The cells of plant seeds store oils in the form of droplets enclosed by membranes. Unlike typical biological membranes, this oil droplet membrane consists of a single layer of phospholipids rather than a bilayer. Draw a model for a membrane around such an oil droplet. Explain why this arrangement is more stable than a bilayer of phospholipids.

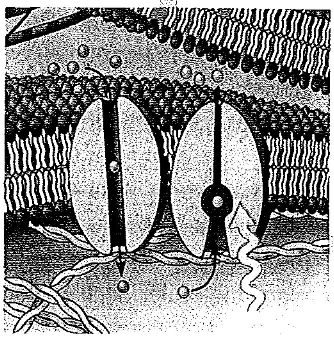
Answers to all questions can be found in Appendix 1.

CHAPTER

4

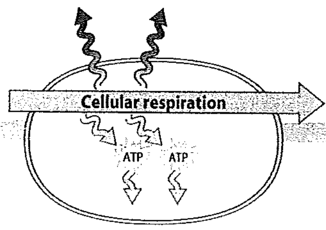
The Working Cell

BIG IDEAS



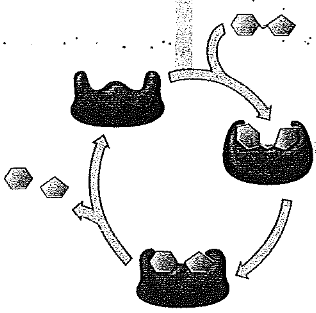
Membrane Structure and Function
(4.1–4.6)

The phospholipid and protein structure of cell membranes enables their many important functions.



Energy and the Cell
(4.7)

A cell's metabolic reactions transform energy, producing ATP, which drives cellular work.



How Enzymes Function
(4.8)

Enzymes speed up a cell's chemical reactions and provide precise control of metabolism.

Membrane Structure and Function

4.1 Membranes are fluid mosaics of lipids and proteins with many functions

The plasma membrane is the edge of life, the boundary that encloses a living cell. In eukaryotic cells, internal membranes partition the cell into specialized compartments. Membranes are composed of a bilayer of phospholipids with embedded and attached proteins. Biologists describe such a structure as a **fluid mosaic**.

In the cell, a membrane remains about as "fluid" as salad oil, with most of its components able to drift about like partygoers moving through a crowded room. Double bonds in the unsaturated fatty acid tails of some phospholipids produce kinks that prevent phospholipids from packing too tightly (see Module 2.7). In animal cell membranes, the steroid cholesterol helps stabilize the membrane at warm temperatures but also helps keep the membrane fluid at lower temperatures.

A membrane is a "mosaic" in having diverse protein molecules embedded in its fluid framework. The word *mosaic* can also refer to the varied functions of these proteins. Different types of cells have different membrane proteins, and the various membranes within a cell each contain a unique collection of proteins.

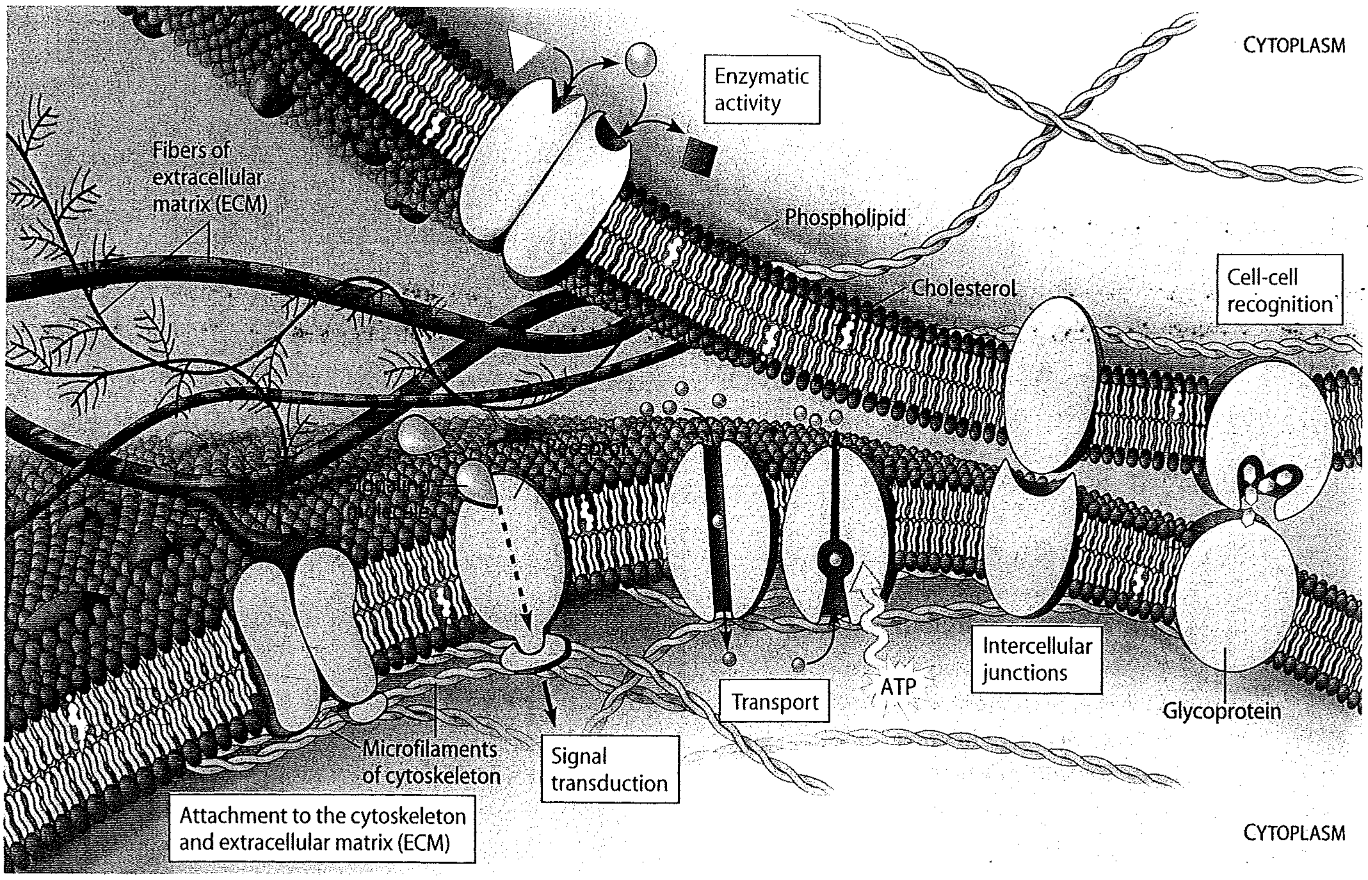
Figure 4.1, which diagrams the plasma membranes of two adjacent cells, illustrates six major functions performed by membrane proteins, represented by the purple oval structures. Some proteins help maintain cell shape and coordinate changes inside and outside the cell through their attachment to the cytoskeleton and extracellular matrix (ECM). Other proteins function as receptors for chemical messengers (signaling molecules) from other cells. The binding of a signaling molecule triggers a change in the protein, which relays the message into the cell, activating molecules that perform specific functions. This message-transfer process is called signal transduction.

Some membrane proteins are enzymes, which may be grouped in a membrane to carry out sequential steps of a metabolic pathway. Membrane glycoproteins may be involved in cell-cell recognition. Their attached carbohydrates function as identification tags that are recognized by membrane proteins of other cells. This recognition allows cells in an embryo to sort into tissues and enables cells of the immune system to recognize and reject foreign cells, such as infectious bacteria. Membrane proteins also participate in the intercellular junctions that attach adjacent cells.

A final critical function is in transport of substances across the membrane. Membranes exhibit **selective permeability**; that is, they allow some substances to cross more easily than others. Many essential ions and molecules, such as glucose, require transport proteins to enter or leave the cell.

? Review the six different types of functions that proteins in a plasma membrane can perform.

Attachment to the cytoskeleton and ECM, signal transduction, enzymatic activity, cell-cell recognition, intercellular joining, and transport.



▲ **Figure 4.1** Some functions of membrane proteins

4.2 Passive transport is diffusion across a membrane with no energy investment

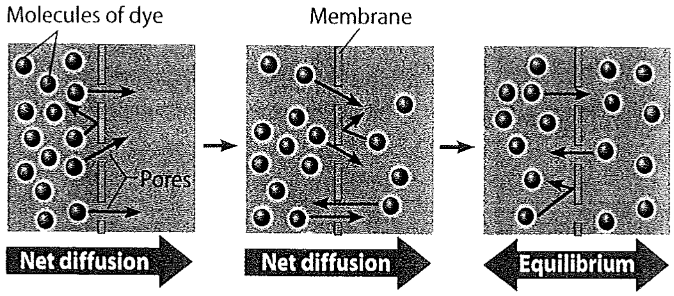
Molecules vibrate and move randomly as a result of a type of energy called thermal motion (heat). One result of this motion is **diffusion**, the tendency for particles of any kind to spread out evenly in an available space. How might diffusion affect the movement of substances into or out of a cell?

The figures to the right will help you to visualize diffusion across a membrane. **Figure 4.2A** shows a solution of green dye separated from pure water by a membrane. Assume that this membrane has microscopic pores through which dye molecules can move. Thus, we say it is permeable to the dye. Although each molecule moves randomly, there will be a *net* movement from the side of the membrane where dye molecules are more concentrated to the side where they are less concentrated. Put another way, the dye diffuses down its **concentration gradient**. Eventually, the solutions on both sides will have equal concentrations of dye. At this dynamic equilibrium, molecules still move back and forth, but there is no *net* change in concentration on either side of the membrane.

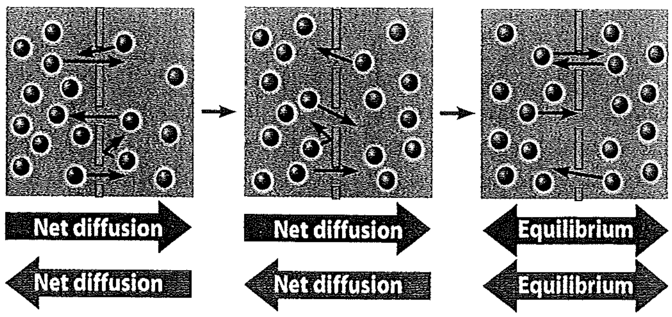
Figure 4.2B illustrates the important point that two or more substances diffuse independently of each other; that is, each diffuses down its own concentration gradient.

Because a cell does not have to do work when molecules diffuse across its membrane, such movement across a membrane is called **passive transport**. Much of the traffic across cell membranes occurs by diffusion. For example, diffusion down concentration gradients is the sole means by which oxygen (O_2), essential for metabolism, enters your cells and carbon dioxide (CO_2), a metabolic waste, passes out of them.

Both O_2 and CO_2 are small, nonpolar molecules that diffuse easily across the phospholipid bilayer of a membrane.



▲ **Figure 4.2A** Passive transport of one type of molecule



▲ **Figure 4.2B** Passive transport of two types of molecules

But can ions and polar molecules also diffuse across the hydrophobic interior of a membrane? They can if they are moving down their concentration gradients and if they have transport proteins to help them cross.

? **Why is diffusion across a membrane called passive transport?**

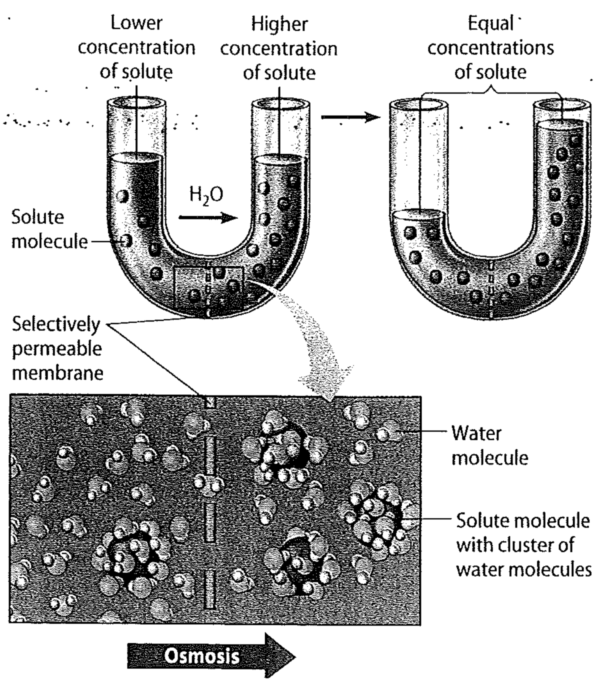
The cell does not expend energy to transport substances that are diffusing down their concentration gradients.

4.3 Osmosis is the diffusion of water across a membrane

One of the most important substances that crosses membranes by passive transport is water. Let's explore a physical model of the diffusion of water across a selectively permeable membrane, a process called **osmosis**. Remember that a selectively permeable membrane allows some substances to cross more easily than others.

The top of **Figure 4.3** shows what happens if a membrane permeable to water but not to a solute (such as glucose) separates two solutions with different concentrations of solute. (A solute is a substance that dissolves in a liquid solvent, producing a solution.) The solution on the right side initially has a higher concentration of solute than that on the left. As you can see, water crosses the membrane until the solute concentrations are equal on both sides.

In the close-up view at the bottom of Figure 4.3, you can see what happens at the molecular level. Polar water molecules cluster around hydrophilic (water-loving) solute molecules. The effect is that on the right side, there are fewer water molecules available to cross the membrane. The less concentrated solution on the left, with fewer solute molecules,



▲ **Figure 4.3** Osmosis, the diffusion of water across a membrane

has more water molecules *free* to move. There is a net movement of water down its own concentration gradient, from the solution with more free water molecules (and lower solute concentration) to that with fewer free water molecules (and higher solute concentration). The result of this water movement is the difference in water levels you see at the top right of Figure 4.3.

Let's now apply to living cells what we have learned about osmosis in artificial systems.

? Indicate the direction of net water movement between two solutions—a 0.5% sucrose solution and a 2% sucrose solution—separated by a membrane not permeable to sucrose.

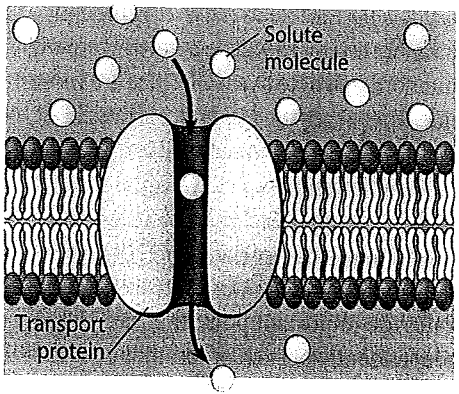
From the 0.5% sucrose solution (lower solute concentration) to the 2% sucrose solution (higher solute concentration).

4.4 Transport proteins can facilitate diffusion across membranes

Recall that nonpolar, hydrophobic molecules can dissolve in the lipid bilayer of a membrane and cross it with ease. Polar or charged substances, meanwhile, can move across a membrane with the help of specific transport proteins in a process called **facilitated diffusion**. Without the transport protein, the substance cannot cross the membrane or it diffuses across it too slowly to be useful to the cell. Facilitated diffusion is a type of passive transport because it does not require energy. As in all passive transport, the driving force is the concentration gradient.

Figure 4.4 shows a common type of transport protein, which provides a hydrophilic channel that some molecules or ions use as a tunnel through the membrane. Another type of transport protein binds its passenger, changes shape, and releases its passenger on the other side. In both cases, the transport protein is specific for the substance it helps move across the membrane. The greater the number of transport proteins for a particular solute in a membrane, the faster the solute's rate of diffusion across the membrane.

Substances that use facilitated diffusion for crossing cell membranes include a number of sugars, amino acids, ions—and even water. The water molecule is very small, but because it is polar, its diffusion through a membrane's hydrophobic interior is relatively slow. The very rapid diffusion of water into and out of certain cells, such as plant cells, kidney cells, and red blood cells, is made possible by a protein channel called an **aquaporin**. A single aquaporin allows the entry or exit of up to 3 billion water molecules per second—a tremendous increase in water transport over simple diffusion.



◀ **Figure 4.4** Transport protein providing a channel for the diffusion of a specific solute across a membrane

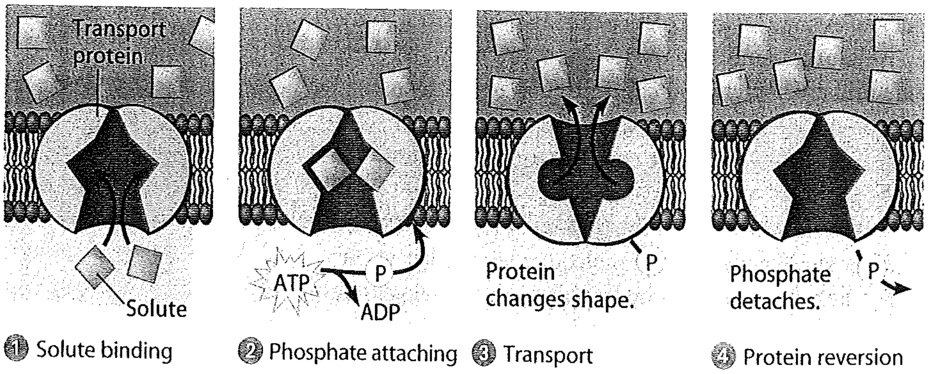
? How do transport proteins contribute to a membrane's selective permeability?

Because they are specific for the solutes they transport, the numbers and kinds of transport proteins affect a membrane's permeability to various solutes.

4.5 Cells expend energy in the active transport of a solute

In **active transport**, a cell must expend energy to move a solute *against* its concentration gradient—that is, across a membrane toward the side where the solute is more concentrated. The energy molecule ATP supplies the energy for most active transport.

Figure 4.5 shows a simple model of an active transport system that pumps a solute out of the cell against its concentration gradient. ① The process begins when solute molecules on the cytoplasmic side of the plasma membrane attach to specific binding sites on the transport protein. ② ATP then transfers a phosphate group to the transport protein, ③ causing the protein to change shape in such a way that the solute is released on the other side of the membrane. ④ The phosphate group detaches, and the transport protein returns to its original shape.



▲ **Figure 4.5** Active transport of a solute across a membrane

Active transport allows a cell to maintain internal concentrations of small molecules and ions that are different from concentrations in its surroundings. For example, the inside of an animal cell has a higher concentration of potassium ions (K^+) and a lower concentration of sodium ions (Na^+) than the solution outside the cell. The generation of nerve signals depends on these concentration differences, which a transport protein called the sodium-potassium pump helps maintain by shuttling Na^+ and K^+ against their concentration gradients.

? Cells actively transport Ca^{2+} out of the cell. Is calcium more concentrated inside or outside of the cell? Explain.

Outside: Active transport moves calcium against its concentration gradient.

4.6 Exocytosis and endocytosis transport large molecules across membranes

So far, we've focused on how water and small solutes enter and leave cells. The story is different for large molecules.

A cell uses the process of **exocytosis** (from the Greek *exo*, outside, and *kytos*, cell) to export bulky materials such as proteins or polysaccharides. As you saw in Figure 3.10, a transport vesicle filled with macromolecules buds from the Golgi apparatus and moves to the plasma membrane. Once there, the vesicle fuses with the plasma membrane, and the vesicle's contents spill out of the cell when the vesicle membrane becomes part of the plasma membrane. When we weep, for instance, cells in our tear glands use exocytosis to export a salty solution containing proteins. In another example, certain cells in the pancreas manufacture the hormone insulin and secrete it into the bloodstream by exocytosis.

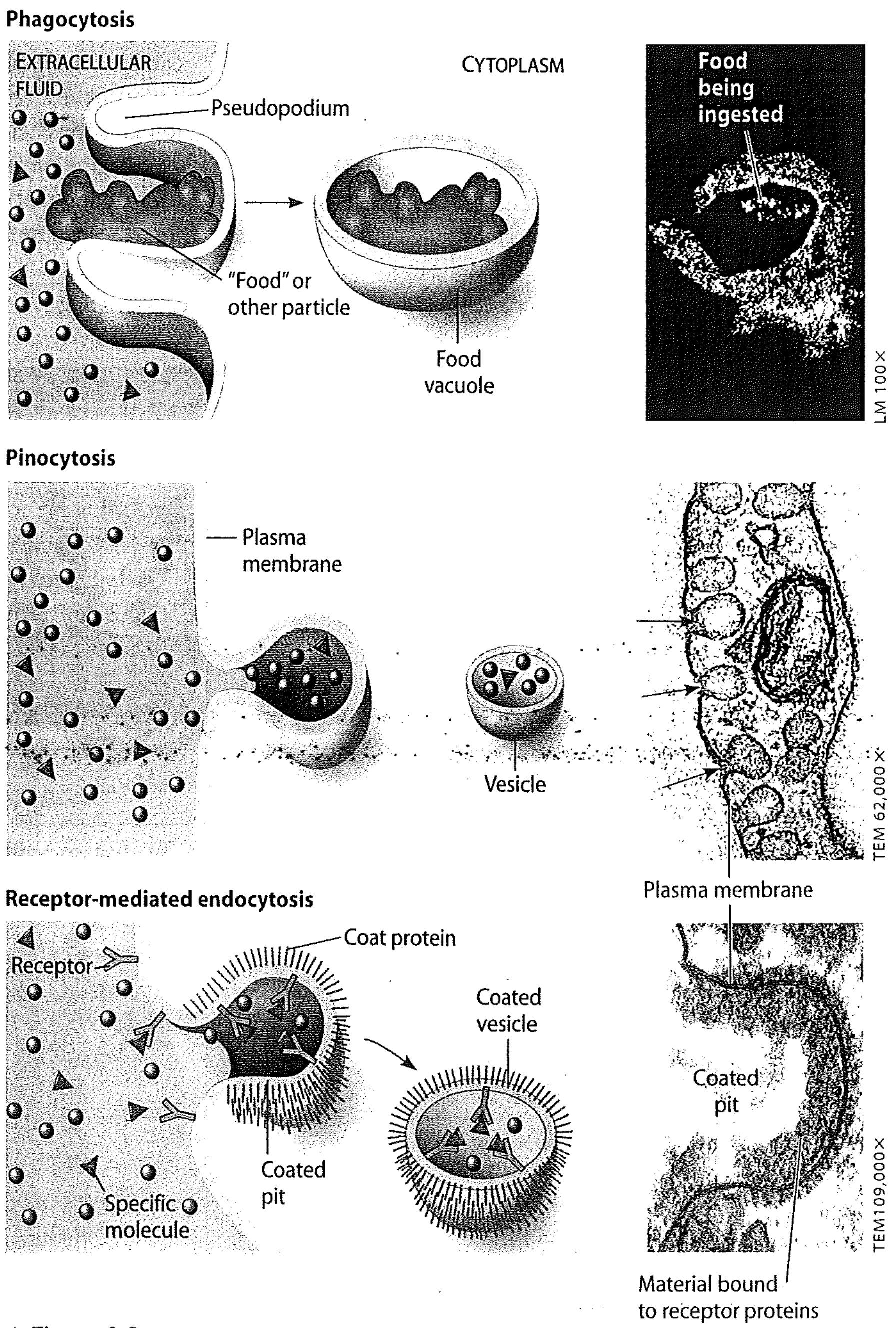
Endocytosis (*endo*, inside) is a transport process that is the opposite of exocytosis. In endocytosis, a cell takes in large molecules. A depression in the plasma membrane pinches in and forms a vesicle enclosing material that had been outside the cell.

Figure 4.6 shows three kinds of endocytosis. The top diagram illustrates **phagocytosis**, or "cellular eating." A cell engulfs a particle by wrapping extensions called pseudopodia around it and packaging it within a membrane-enclosed sac large enough to be called a vacuole. As described in Module 3.8, the vacuole then fuses with a lysosome, whose hydrolytic enzymes digest the contents of the vacuole. The micrograph on the top right shows an amoeba taking in a food particle via phagocytosis.

The center diagram shows **pinocytosis**, or "cellular drinking." The cell "gulps" droplets of fluid into tiny vesicles. Pinocytosis is not specific; it takes in any and all solutes dissolved in the droplets. The micrograph in the middle shows pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel.

? As a cell grows, its plasma membrane expands. Does this involve endocytosis or exocytosis? Explain.

Exocytosis: When a transport vesicle fuses with the plasma membrane, its contents are released and the vesicle membrane adds to the plasma membrane.



▲ **Figure 4.6** Three kinds of endocytosis

Energy and the Cell

4.7 Cells transform energy as they perform work

The title of this chapter is "The Working Cell." But just what type of work does a cell do? You just learned that a cell actively transports substances across membranes. The cell also builds those membranes and the proteins embedded in them. A cell is a miniature chemical factory in which thousands of reactions occur within a microscopic space. Some of these reactions release energy; others require energy. To understand how the cell works, you must have a basic knowledge of energy.

Forms of Energy We can define **energy** as the capacity to cause change or to perform work. There are two basic forms of energy: kinetic energy and potential energy. **Kinetic energy** is the energy of motion. Moving objects can perform work by transferring motion to other matter. For example, the movement of your legs can push bicycle pedals, turning the wheels and moving you and your bike up a hill. **Heat**, or thermal energy, is a type of kinetic energy associated with the random movement of atoms or molecules. Light, also a type of kinetic energy, can be harnessed to power photosynthesis.

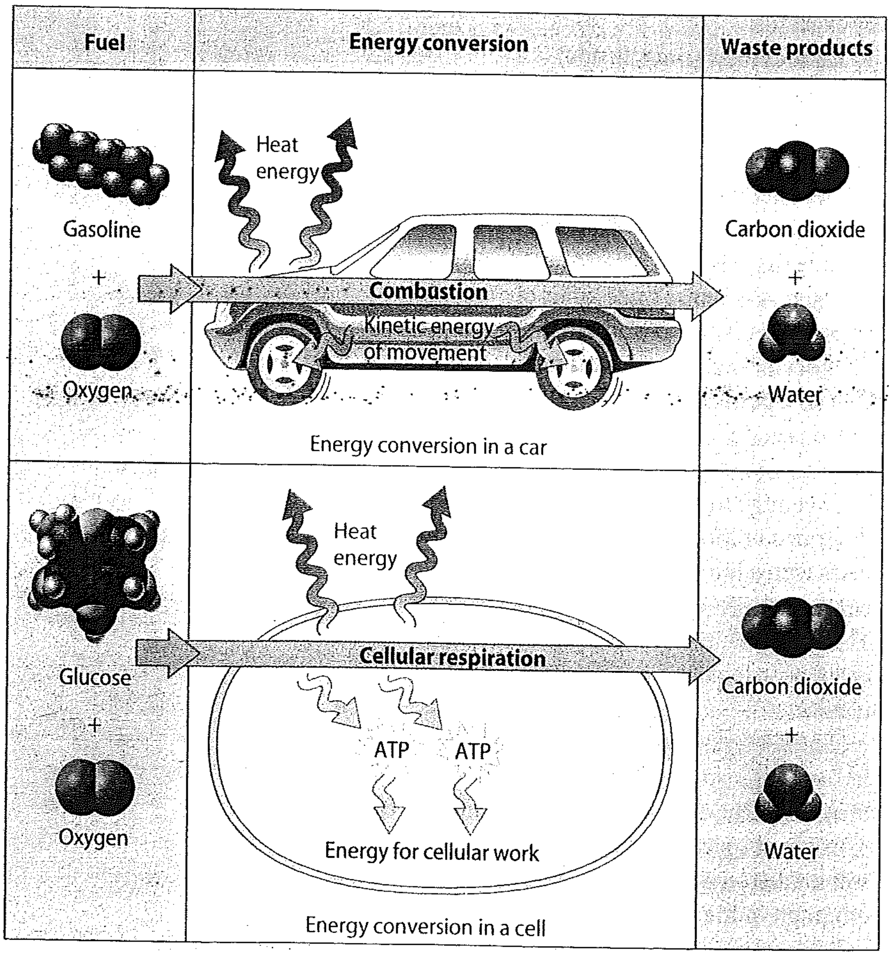
Potential energy, the second main form of energy, is energy that matter possesses as a result of its location or structure. Water behind a dam and you on your bicycle at the top of a hill possess potential energy. Molecules possess potential energy because of the arrangement of electrons in the bonds between their atoms. **Chemical energy** is the potential energy available for release in a chemical reaction. Chemical energy is the most important type of energy for living organisms; it is the energy that can be transformed to power the work of the cell.

Energy Transformations **Thermodynamics** is the study of energy transformations that occur in a collection of matter. Scientists use the word *system* for the matter under study and refer to the rest of the universe—everything outside the system—as the *surroundings*. A system can be an electric power plant, a single cell, or the entire planet. An organism is an open system; that is, it exchanges both energy and matter with its surroundings.

The **first law of thermodynamics,** also known as the law of energy conservation, states that the energy in the universe is constant. Energy can be transferred and transformed, but it cannot be created or destroyed. A power plant does not create energy; it merely converts it from one form (such as the energy stored in coal) to the more convenient form of electricity. A plant cell converts light energy to chemical energy; it, too, is an energy transformer, not an energy producer.

If energy cannot be destroyed, then why can't organisms simply recycle their energy? It turns out that during every transfer or transformation, some energy becomes unusable—unavailable to do work. In most energy transformations, some energy is converted to heat, a disordered form of energy. Scientists use a quantity called **entropy** as a measure of disorder, or randomness. The more randomly arranged a collection of matter is, the greater its entropy. According to the **second law of thermodynamics**, energy conversions increase the entropy (disorder) of the universe.

Figure 4.7 compares a car and a cell to show how energy can be transformed and how entropy increases as a result. Automobile engines and living cells use the same basic process to make the chemical energy of their fuel available for work. The engine mixes oxygen with gasoline in an explosive chemical reaction that pushes the pistons, which eventually move the wheels. The waste products emitted from the exhaust pipe



▲ **Figure 4.7** Energy transformations (with an increase in entropy) in a car and a cell

are mostly carbon dioxide and water, energy-poor, simple molecules. Only about 25% of the chemical energy stored in gasoline is converted to the kinetic energy of the car's movement; the rest is lost as heat.

Cells also use oxygen in reactions that release energy from fuel molecules. In the process called **cellular respiration**, the chemical energy stored in organic molecules is converted to a form that the cell can use to perform work. Just like for the car, the waste products are mostly carbon dioxide and water. Cells are more efficient than car engines, however, converting about 34% of the chemical energy in their fuel to energy for cellular work. The other 66% generates heat, which explains why vigorous exercise makes you so warm.

According to the second law of thermodynamics, energy transformations result in the universe becoming more disordered. How, then, can we account for biological order? A cell creates intricate structures from less organized materials. Although this increase in order corresponds to a decrease in entropy, it is accomplished at the expense of ordered forms of matter and energy taken in from the surroundings. As shown in Figure 4.7, cells extract the chemical energy of glucose and return disordered heat and lower-energy carbon dioxide and water to the surroundings. In a thermodynamic sense, a cell is an island of low entropy in an increasingly random universe.

? How does the second law of thermodynamics explain the diffusion of a solute across a membrane?

Diffusion across a membrane results in equal concentrations of solute, which is a more disordered arrangement (higher entropy) than a high concentration on one side and a low concentration on the other.

How Enzymes Function

4.8 Enzymes speed up the cell's chemical reactions by lowering energy barriers

Your room gets messier; water flows downhill; sugar crystals dissolve in your coffee. Ordered structures tend toward disorder, and high-energy systems tend to change toward a more stable state of low energy. Proteins, DNA, carbohydrates, lipids—most of the complex molecules of your cells are rich in potential energy. Why don't these high-energy, ordered molecules spontaneously break down into less ordered, lower-energy molecules? They remain intact for the same reason that wood doesn't normally burst into flames or the gas in an automobile's gas tank doesn't spontaneously explode.

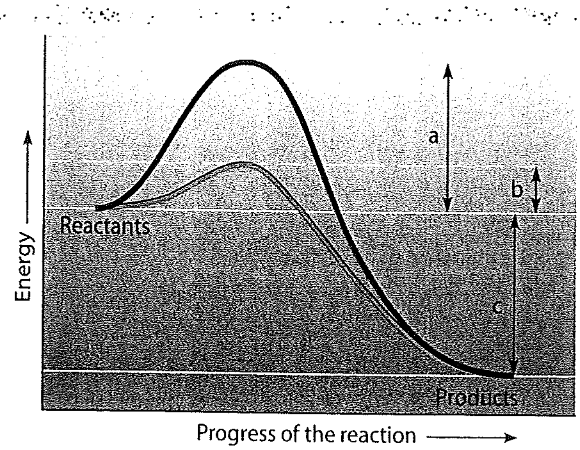
There is an energy barrier that must be overcome before a chemical reaction can begin. Energy must be absorbed to contort or weaken bonds in reactant molecules so that they can break and new bonds can form. We call this the **activation energy** (abbreviated E_A for energy of activation). We can think of E_A as the amount of energy needed for reactant molecules to move "uphill" to a higher-energy, unstable state so that the "downhill" part of a reaction can begin.

The energy barrier of E_A protects the highly ordered molecules of your cells from spontaneously breaking down. But now we have a dilemma. Life depends on countless chemical reactions that constantly change a cell's molecular makeup. Most of the essential reactions of metabolism must occur quickly and precisely for a cell to survive. How can the specific reactions that a cell requires get over that energy barrier?

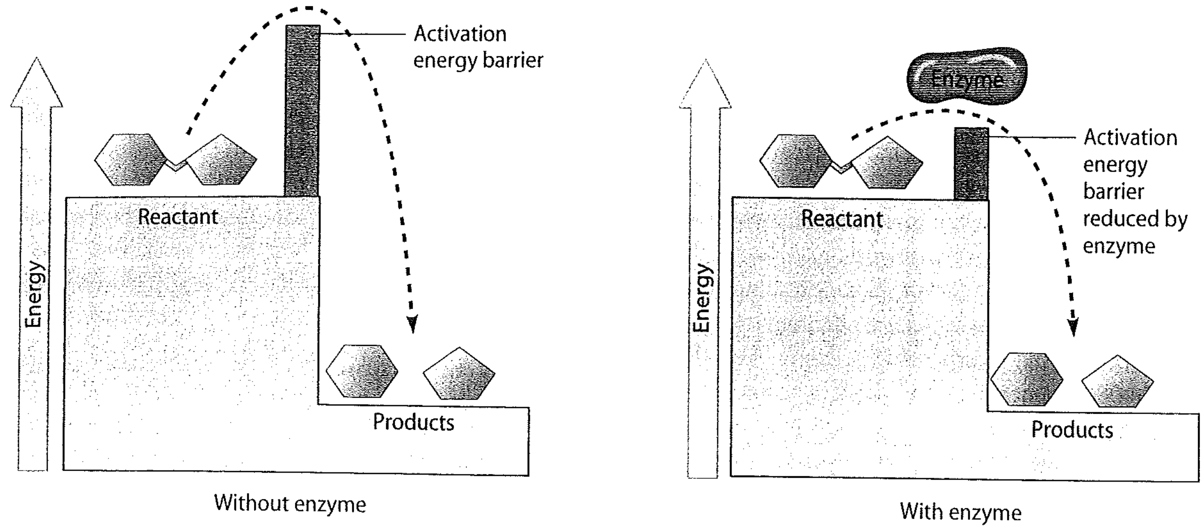
One way to speed reactions is to add heat. Heat speeds up molecules and agitates atoms so that bonds break more easily and reactions can proceed. Certainly, adding a match to kindling will start a fire, and the firing of a spark plug ignites gasoline in an engine. But heating a cell would speed up all chemical reactions, not just the necessary ones, and too much heat would kill the cell.

The answer to our dilemma lies in **enzymes**—molecules that function as biological catalysts, increasing the rate of a reaction without being consumed by the reaction. Almost all enzymes are proteins, although some RNA molecules can also function as enzymes. An enzyme speeds up a reaction by lowering the E_A needed for a reaction to begin. **Figure 4.8** compares a reaction without (left) and with (right) an enzyme. Notice how much easier it is for the reactant to get over the activation energy barrier when an enzyme is involved.

? The graph below illustrates the course of a reaction with and without an enzyme. Which curve represents the enzyme-catalyzed reaction? What energy changes are represented by the lines labeled a, b, and c?



The red (lower) curve is the enzyme-catalyzed reaction. Line a is E_A without enzyme; b is E_A with enzyme; c is the change in energy between reactants and products, which is the same for both the catalyzed and uncatalyzed reactions.



▲ **Figure 4.8** The effect of an enzyme in lowering E_A

CHAPTER 4 REVIEW

Reviewing the Concepts

Membrane Structure and Function (4.1–4.6)

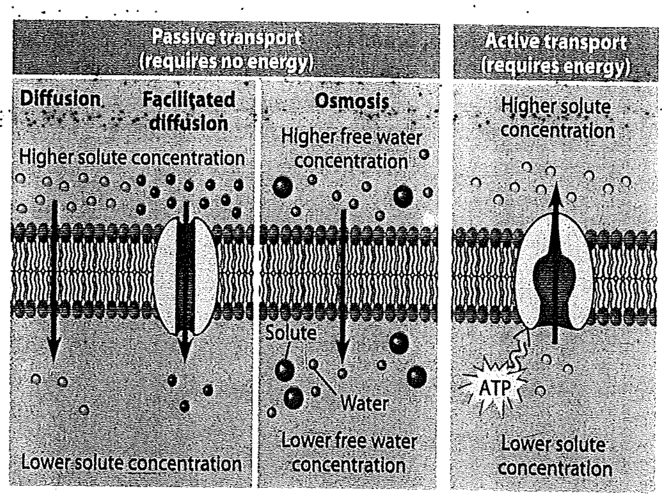
4.1 Membranes are fluid mosaics of lipids and proteins with many functions. The proteins embedded in a membrane's phospholipid bilayer perform various functions.

4.2 Passive transport is diffusion across a membrane with no energy investment. Solutes diffuse across membranes down their concentration gradients.

4.3 Osmosis is the diffusion of water across a membrane.

4.4 Transport proteins can facilitate diffusion across membranes.

4.5 Cells expend energy in the active transport of a solute.



4.6 Exocytosis and endocytosis transport large molecules across membranes. A vesicle may fuse with the membrane and expel its contents (exocytosis), or the membrane may fold inward, enclosing material from the outside (endocytosis).

Energy and the Cell (4.7)

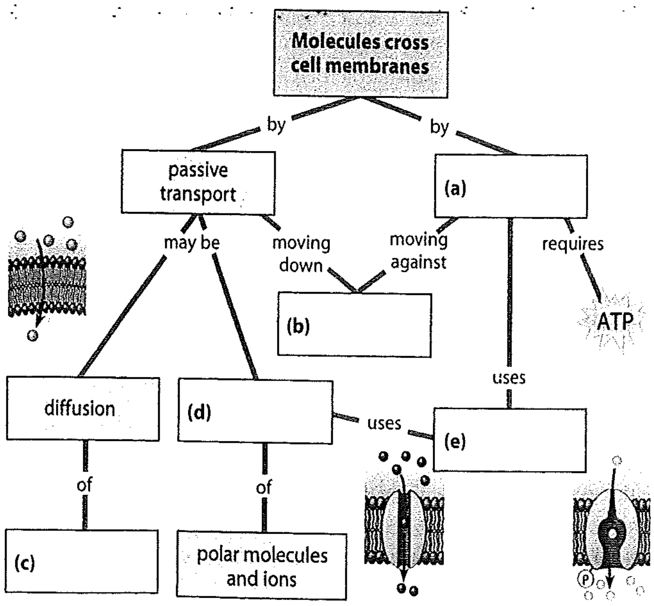
4.7 Cells transform energy as they perform work. Kinetic energy is the energy of motion. Potential energy is energy stored in the location or structure of matter. Chemical energy is potential energy available for release in a chemical reaction. According to the laws of thermodynamics, energy can change form but cannot be created or destroyed, and energy transformations increase disorder, or entropy, with some energy being lost as heat.

How Enzymes Function (4.8)

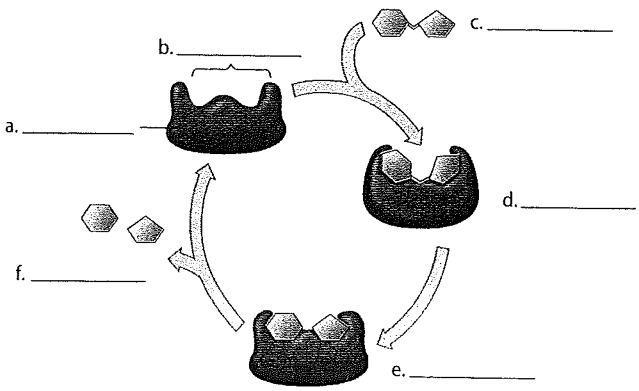
4.8 Enzymes speed up the cell's chemical reactions by lowering energy barriers. Enzymes are protein catalysts that decrease the activation energy (E_A) needed to begin a reaction.

Connecting the Concepts

1. Fill in the following concept map to review the processes by which molecules move across membranes.



2. Label the parts of the following diagram illustrating the catalytic cycle of an enzyme.



Testing Your Knowledge

Multiple Choice

3. Which best describes the structure of a cell membrane?
   a. proteins between two bilayers of phospholipids
   b. proteins embedded in a bilayer of phospholipids
   c. a bilayer of protein coating a layer of phospholipids
   d. phospholipids between two layers of protein
   e. cholesterol embedded in a bilayer of phospholipids

4. Consider the following: chemical bonds in the gasoline in a car's gas tank and the movement of the car along the road; a biker at the top of a hill and the ride he took to get there. The first parts of these situations illustrate ______, and the second parts illustrate ______.
   a. the first law of thermodynamics ... the second law
   b. kinetic energy ... potential energy
   c. an exergonic reaction ... an endergonic reaction
   d. potential energy ... kinetic energy
   e. the second law of thermodynamics ... the first law

5. The sodium concentration in a cell is 10 times less than the concentration in the surrounding fluid. How can the cell move sodium out of the cell? (*Explain.*)
   a. passive transport
   b. diffusion
   c. active transport
   d. osmosis
   e. any of these processes

6. The synthesis of ATP from ADP and P
   a. is an exergonic process.
   b. involves the hydrolysis of a phosphate bond.
   c. transfers a phosphate, priming a protein to do work.
   d. stores energy in a form that can drive cellular work.
   e. releases energy.

7. Facilitated diffusion across a membrane requires ______ and moves a solute ______ its concentration gradient.
   a. transport proteins ... up (against)
   b. transport proteins ... down
   c. energy ... up
   d. energy and transport proteins ... up
   e. energy and transport proteins ... down

Describing, Comparing, and Explaining

8. What are aquaporins? Where would you expect to find them?

9. What are the main types of cellular work? How does ATP provide the energy for this work?

10. Why is the barrier of the activation energy beneficial for organic molecules? Explain how enzymes lower E_A.

11. How do the components and structure of cell membranes relate to the functions of membranes?

12. Sometimes inhibitors can be harmful to a cell; often they are beneficial. Explain.

Applying the Concepts

13. Explain how each of the following food preservation methods would interfere with a microbe's enzyme activity and ability to break down food: canning (heating), freezing, pickling (soaking in acetic acid), salting.

14. A biologist performed two series of experiments on lactase, the enzyme that hydrolyzes lactose to glucose and galactose. First, she made up 10% lactose solutions containing different concentrations of enzyme and measured the rate at which galactose was produced (grams of galactose per minute). Results of these experiments are shown in Table A below. In the second series of experiments (Table B), she prepared 2% enzyme solutions containing different concentrations of lactose and again measured the rate of galactose production.

Table A: Rate and Enzyme Concentration

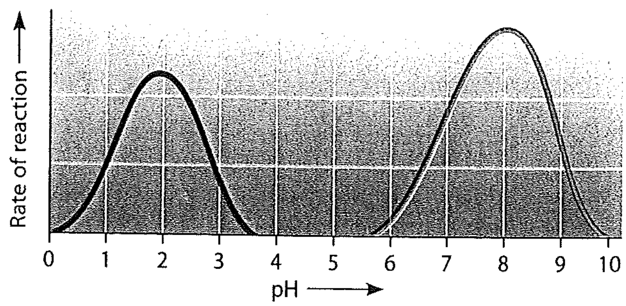
Lactose concentration	10%	10%	10%	10%	10%
Enzyme concentration	0%	1%	2%	4%	8%
Reaction rate	0	25	50	100	200

Table B: Rate and Substrate Concentration

Lactose concentration	0%	5%	10%	20%	30%
Enzyme concentration	2%	2%	2%	2%	2%
Reaction rate	0	25	50	65	65

   a. Graph and explain the relationship between the reaction rate and the enzyme concentration.
   b. Graph and explain the relationship between the reaction rate and the substrate concentration. How and why did the results of the two experiments differ?

15. The following graph shows the rate of reaction for two different enzymes: One is pepsin, a digestive enzyme found in the stomach; the other is trypsin, a digestive enzyme found in the intestine. As you may know, gastric juice in the stomach contains hydrochloric acid. Which curve belongs to which enzyme?



A lysosome, a digestive organelle in a cell, has an internal pH of around 4.5. Draw a curve on the graph that you would predict for a lysosomal enzyme, labeling its optimal pH.

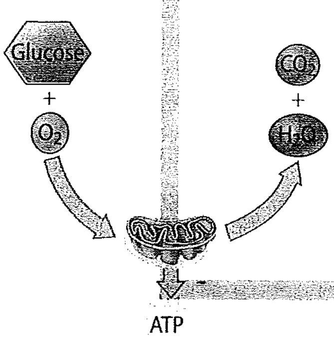
Answers to all questions can be found in Appendix 1.

CHAPTER

5

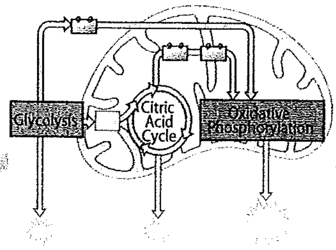
How Cells Harvest Chemical Energy

BIG IDEAS



Cellular Respiration: Aerobic Harvesting of Energy (5.1–5.4)

Cellular respiration oxidizes fuel molecules and generates ATP for cellular work.



Stages of Cellular Respiration (5.5–5.6)

The main stages of cellular respiration are glycolysis, the citric acid cycle, and oxidative phosphorylation.

Fermentation: Anaerobic Harvesting of Energy (5.7)

Fermentation regenerates NAD^+, allowing glycolysis and ATP production to continue without oxygen.

Connections Between Metabolic Pathways (5.8–5.9)

The breakdown pathways of cellular respiration intersect with biosynthetic pathways.

Cellular Respiration: Aerobic Harvesting of Energy

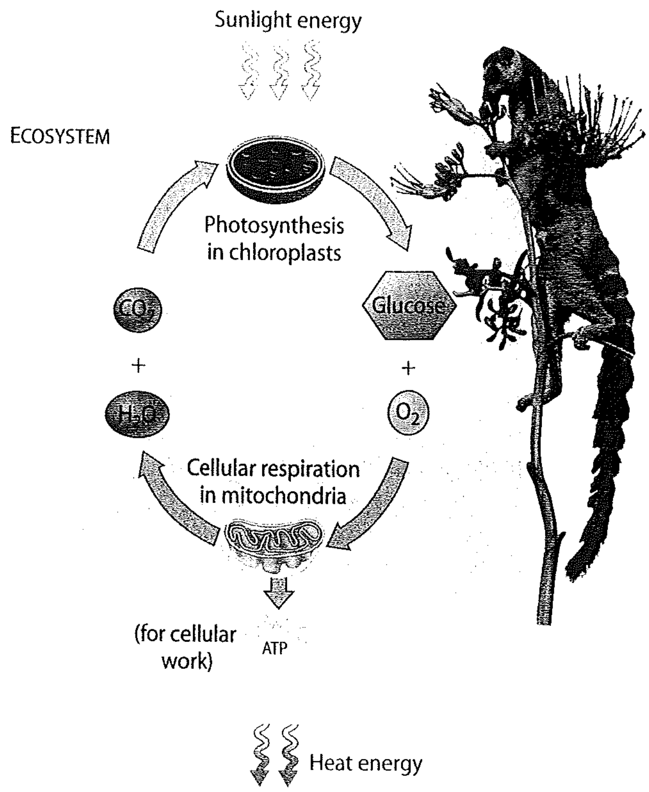
5.1 Photosynthesis and cellular respiration provide energy for life

Life requires energy. In almost all ecosystems, that energy ultimately comes from the sun. Photosynthesis, the process by which the sun's energy is captured, is the topic of Chapter 6. But a brief overview here of the relationship between photosynthesis and cellular respiration will illustrate how these two processes provide energy for life **(Figure 5.1)**. In photosynthesis, which takes place in a plant cell's chloroplasts, the energy of sunlight is used to rearrange the atoms of carbon dioxide (CO_2) and water (H_2O) to produce glucose and oxygen (O_2). The lemur in Figure 5.1 obtains energy for leaping from tree to tree by eating plants. In **cellular respiration**, O_2 is consumed as glucose is broken down to CO_2 and H_2O; the cell captures the energy released in ATP. Cellular respiration takes place in the mitochondria of almost all eukaryotic cells.

This figure also shows that in these energy conversions, some energy is lost as heat. Life on Earth is solar powered, and energy makes a one-way trip through an ecosystem. Chemicals, however, are recycled. The CO_2 and H_2O released by cellular respiration are converted through photosynthesis to glucose and O_2, which are then used in respiration.

? What is misleading about the following statement? "Plant cells perform photosynthesis, and animal cells perform cellular respiration."

The statement implies that cellular respiration does not occur in plant cells. In fact, almost all eukaryotic cells use cellular respiration to obtain energy for their cellular work.



▲ **Figure 5.1** The connection between photosynthesis and cellular respiration

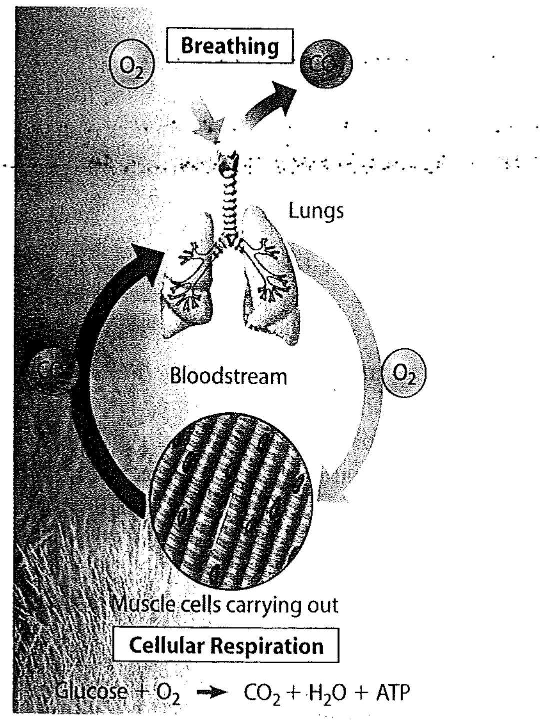
5.2 Breathing supplies O_2 for use in cellular respiration and removes CO_2

We often use the word *respiration* as a synonym for "breathing," the meaning of its Latin root. In that sense of the word, respiration refers to an exchange of gases: An organism obtains O_2 from its environment and releases CO_2 as a waste product. Biologists also define respiration as the aerobic (oxygen-requiring) harvesting of energy from food molecules by cells. This process is called cellular respiration to distinguish it from breathing.

Breathing and cellular respiration are closely related. As the runner in **Figure 5.2** breathes in air, the lungs take up O_2 and pass it to the bloodstream. The bloodstream carries the O_2 to muscle cells. Mitochondria in the muscle cells use the O_2 in cellular respiration to harvest energy from glucose and other organic molecules and generate ATP. Muscle cells use ATP to contract. The runner's bloodstream and lungs also perform the vital function of disposing of the CO_2 waste, which, as you can see by the equation at the bottom of the figure, is produced in cellular respiration.

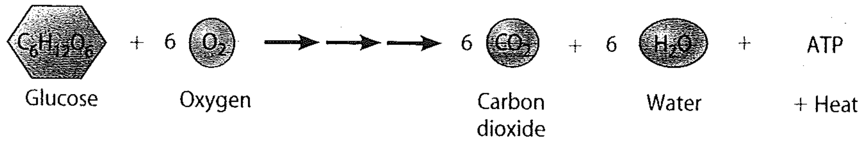
? How is your breathing related to your cellular respiration?

In breathing, CO_2 and O_2 are exchanged between your lungs and the air. In cellular respiration, cells use the O_2 obtained through breathing to break down fuel, releasing CO_2 as a waste product.



▲ **Figure 5.2** The connection between breathing and cellular respiration

5.3 Cellular respiration banks energy in ATP molecules



▲ **Figure 5.3** Summary equation for cellular respiration: $C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O$ + Energy (ATP + Heat)

As the runner example in Figure 5.2 implies, oxygen usage is only a means to an end. Generating ATP for cellular work is the fundamental function of cellular respiration.

The balanced chemical equation in **Figure 5.3** summarizes cellular respiration as carried out by cells that use O_2 in harvesting energy from glucose. The simple sugar glucose ($C_6H_{12}O_6$) is the fuel that cells use most often, although other organic molecules can also be "burned" in cellular respiration. The equation tells us that the atoms of the reactant molecules $C_6H_{12}O_6$ and O_2 are rearranged to form the products CO_2 and H_2O. In this exergonic process, the chemical energy of the bonds in glucose is released and stored (or "banked") in the chemical bonds of ATP (see Modules 4.8–4.9). The series of arrows in Figure 5.3 indicates that cellular respiration consists of many steps, not just a single reaction.

Cellular respiration can produce up to 32 ATP molecules for each glucose molecule, a capture of about 34% of the energy originally stored in glucose. The rest of the energy is released as heat (see Module 4.8). This may seem inefficient, but it compares very well with the efficiency of most energy-conversion systems. For instance, the average automobile engine is able to convert only about 25% of the energy in gasoline to the kinetic energy of movement.

How great are the energy needs of a cell? If ATP could not be regenerated through cellular respiration, you would use up nearly your body weight in ATP each day. Let's consider the energy requirements for various human activities next.

? Why are sweating and other body-cooling mechanisms necessary during vigorous exercise?

The demand for ATP is supported by an increased rate of cellular respiration, but about 66% of the energy from food produces heat instead of ATP.

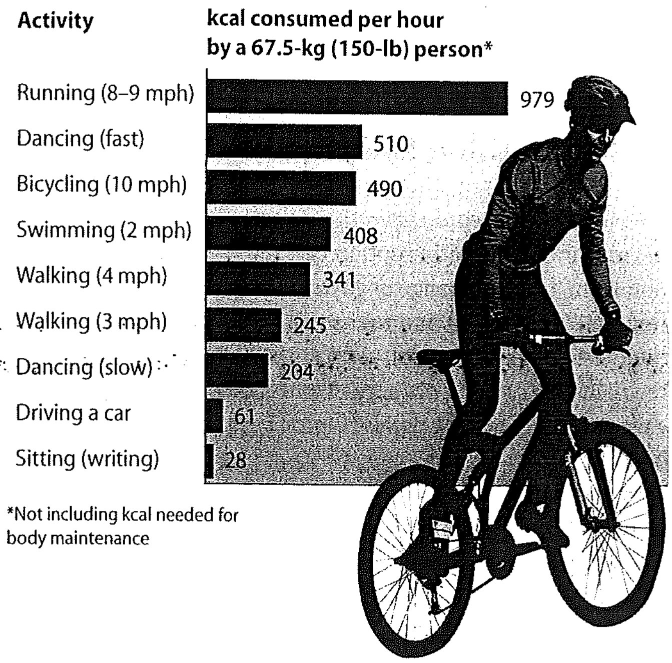
CONNECTION

5.4 The human body uses energy from ATP for all its activities

Your body requires a continuous supply of energy just to stay alive—to keep the heart pumping, to breathe, and to maintain body temperature. Your brain requires a huge amount of energy; its cells burn about 120 grams (g)—a quarter of a pound!—of glucose a day, accounting for about 15% of total oxygen consumption. Maintaining brain cells and other life-sustaining activities uses as much as 75% of the energy a person takes in as food during a typical day.

Above and beyond the energy you need for body maintenance, cellular respiration provides energy for voluntary activities. **Figure 5.4** shows the amount of energy it takes to perform some of these activities. The energy units are **kilocalories (kcal)**, the quantity of heat required to raise the temperature of 1 kilogram (kg) of water by 1°C. (The "Calories" listed on food packages are actually kilocalories, usually signified by a capital C.) The values shown do not include the energy the body consumes for its basic life-sustaining activities. Even sleeping or lying quietly requires energy for metabolism.

The U.S. National Academy of Sciences estimates that the average adult human needs to take in food that provides about 2,200 kcal of energy per day. This includes the energy expended in both maintenance and voluntary activity. We will explore nutritional needs (and the maintenance of a healthy weight) in Chapter 11. But now we begin the study of how cells liberate the energy stored in fuel molecules to produce the ATP used to power the work of cells and thus the activities of the body.



▲ **Figure 5.4** Energy consumed by various activities

? Walking at 3 mph, how far would you have to travel to "burn off" the equivalent of an extra slice of pizza, which has about 475 kcal? How long would that take?

You would have to walk about 6 miles, which would take you about 2 hours. (Now you understand why the most effective exercise for losing weight is pushing away from the table!)

Stages of Cellular Respiration

5.5 Overview: Cellular respiration occurs in three main stages

Cellular respiration consists of a sequence of steps that can be divided into three main stages. **Figure 5.5** gives an overview of the three stages and shows where they occur in a eukaryotic cell. (In prokaryotic cells that use aerobic respiration, these steps occur in the cytoplasm, and the electron transport chain is built into the plasma membrane.)

Stage 1: Glycolysis (shown with an aqua background throughout this chapter) occurs in the cytoplasmic fluid of the cell. Glycolysis begins cellular respiration by breaking glucose into two molecules of a three-carbon compound called pyruvate.

Stage 2: Pyruvate oxidation and the **citric acid cycle** (shown in a salmon color) take place within the mitochondria. Pyruvate is oxidized to a two-carbon compound. The citric acid cycle then completes the breakdown of glucose to carbon dioxide. As suggested by the smaller ATP symbols in the diagram, the cell makes a small amount of ATP during glycolysis and the citric acid cycle. The main function of these first two stages, however, is to supply the third stage of respiration with electrons (shown with gold arrows).

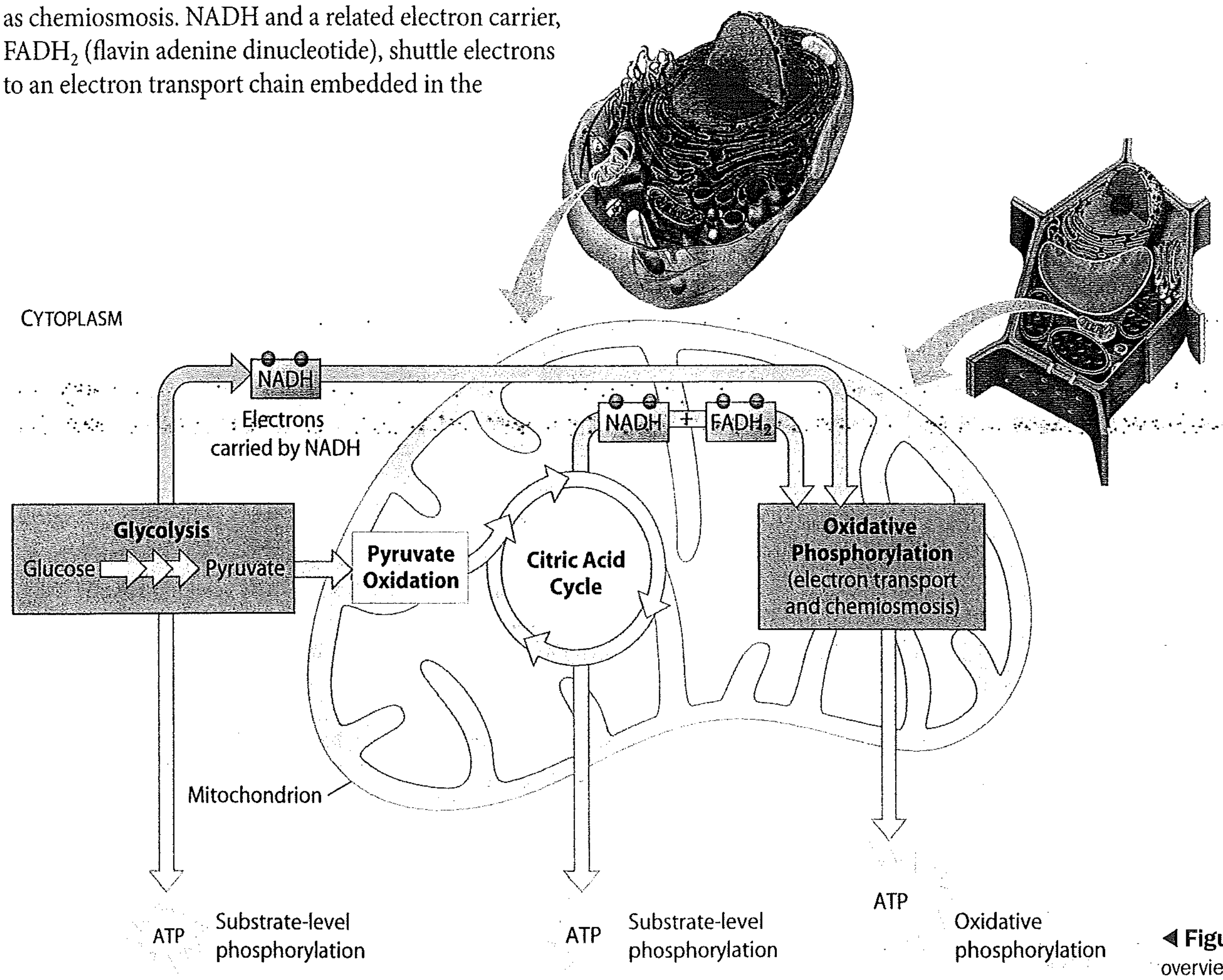
Stage 3: Oxidative phosphorylation (purple background) requires an electron transport chain and a process known as chemiosmosis. NADH and a related electron carrier, $FADH_2$ (flavin adenine dinucleotide), shuttle electrons to an electron transport chain embedded in the inner mitochondrial membrane. Most of the ATP produced by cellular respiration is generated by oxidative phosphorylation, which uses the energy released by the downhill fall of electrons from NADH and $FADH_2$ to O_2 to phosphorylate ADP.

What couples the electron transport chain to ATP synthesis? As the electron transport chain passes electrons down the energy staircase, it also pumps hydrogen ions (H^+) across the inner mitochondrial membrane into the narrow intermembrane space (see Figure 3.10). The result is a concentration gradient of H^+ across the membrane. In **chemiosmosis**, the potential energy of this concentration gradient is used to make ATP. In 1978, British biochemist Peter Mitchell was awarded the Nobel Prize for developing the theory of chemiosmosis.

The small amount of ATP produced in glycolysis and the citric acid cycle is made by substrate-level phosphorylation, a process we discuss next.

? Of the three main stages of cellular respiration represented in Figure 5.5, which one uses oxygen to extract chemical energy from organic compounds?

Oxidative phosphorylation, using the electron transport chain, which eventually transfers electrons to oxygen.



◀ **Figure 5.5** An overview of cellular respiration

5.6 Review: Each molecule of glucose yields many molecules of ATP

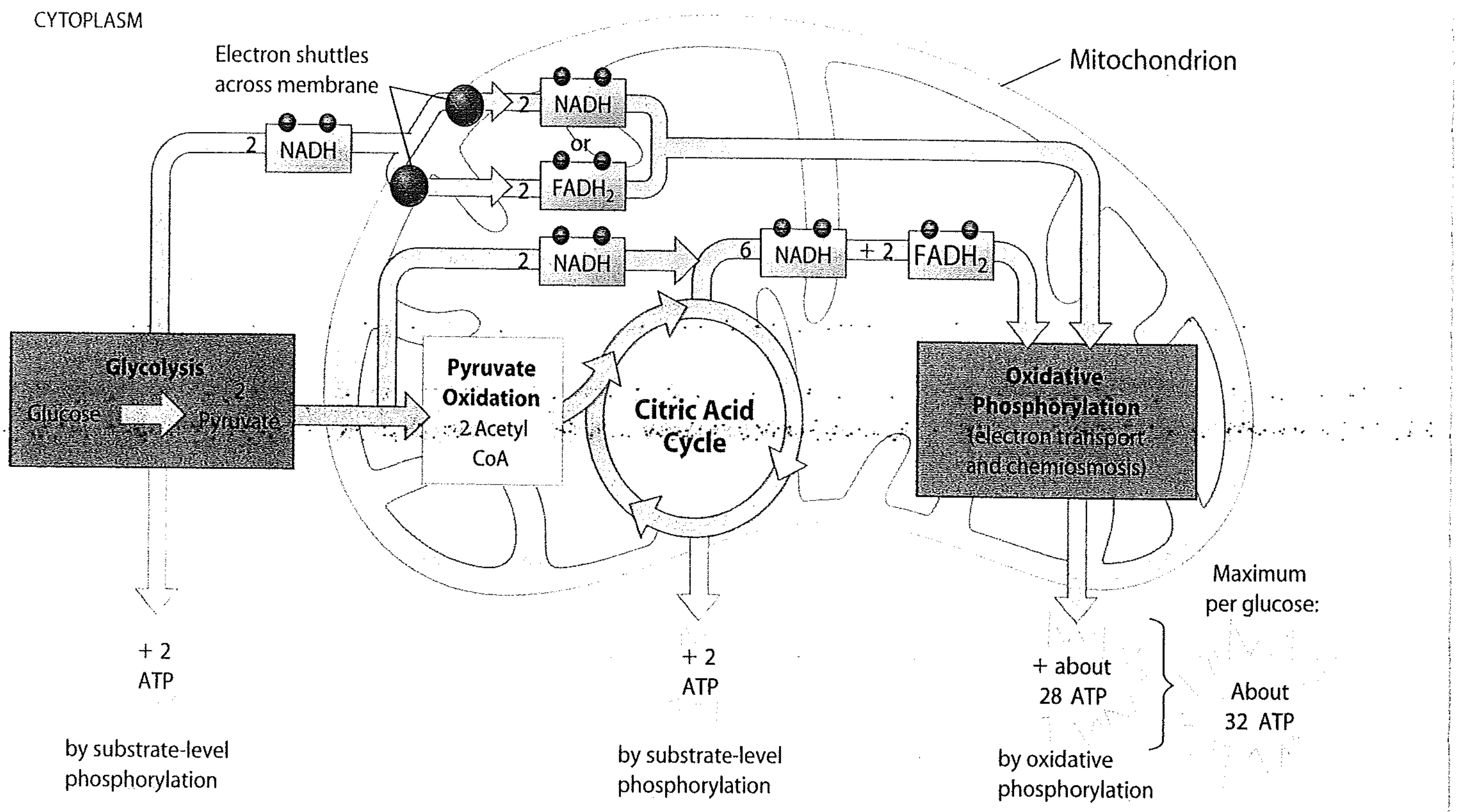
Let's review what the cell accomplishes by oxidizing a molecule of glucose. **Figure 5.6** shows where each stage of cellular respiration occurs in a eukaryotic cell and how much ATP it produces. Starting on the left, glycolysis, which occurs in the cytoplasmic fluid, and the citric acid cycle, which occurs in the mitochondrial matrix, contribute a net total of 4 ATP per glucose molecule by substrate-level phosphorylation. The cell harvests much more energy than this via the carrier molecules NADH and $FADH_2$, which are produced in glycolysis and the citric acid cycle. The energy of the electrons they carry is used to make (according to current estimates) about 28 molecules of ATP by oxidative phosphorylation. Thus, the total yield of ATP molecules per glucose is about 32.

The number of ATP molecules produced cannot be stated exactly for several reasons. As shown in the figure, the NADH produced in glycolysis passes its electrons across the mitochondrial membrane to either NAD^+ or FAD, depending on the type of shuttle system used. Because $FADH_2$ adds its electrons later in the electron transport chain, it contributes less to the H^+ gradient and thus generates less ATP. In addition, some of the energy of the H^+ gradient may be used for work other than ATP production, such as the active transport of pyruvate into the mitochondrion.

More important than the actual number of ATP molecules is the point that a cell can harvest a great deal of energy from glucose—up to about 34% of the molecule's potential energy. Because most of the ATP generated by cellular respiration results from oxidative phosphorylation, the ATP yield depends on an adequate supply of oxygen to the cell. Without oxygen to function as the final electron acceptor, electron transport and ATP production stop. But as we see next, some cells can oxidize organic fuel and generate ATP *without* oxygen.

? What would a cell's net ATP yield per glucose be in the presence of the poison DNP?

4 ATP, all from substrate-level phosphorylation. The uncoupler would destroy the H^+ concentration gradient necessary for chemiosmosis.



▶ **Figure 5.6** An estimated tally of the ATP produced by substrate-level and oxidative phosphorylation in cellular respiration

Fermentation: Anaerobic Harvesting of Energy

5.7 Fermentation enables cells to produce ATP without oxygen

Fermentation is a way of harvesting chemical energy that does not require oxygen. The metabolic pathway that generates ATP during fermentation is glycolysis, the same pathway that functions in the first stage of cellular respiration. Remember that glycolysis uses no oxygen; it simply generates a net gain of 2 ATP while oxidizing glucose to two molecules of pyruvate and reducing NAD^+ to NADH. The yield of 2 ATP is certainly a lot less than the possible 32 ATP per glucose generated during aerobic respiration, but it is enough to keep your muscles contracting for a short period of time when oxygen is scarce. And many microorganisms supply all their energy needs with the 2 ATP per glucose yield of glycolysis.

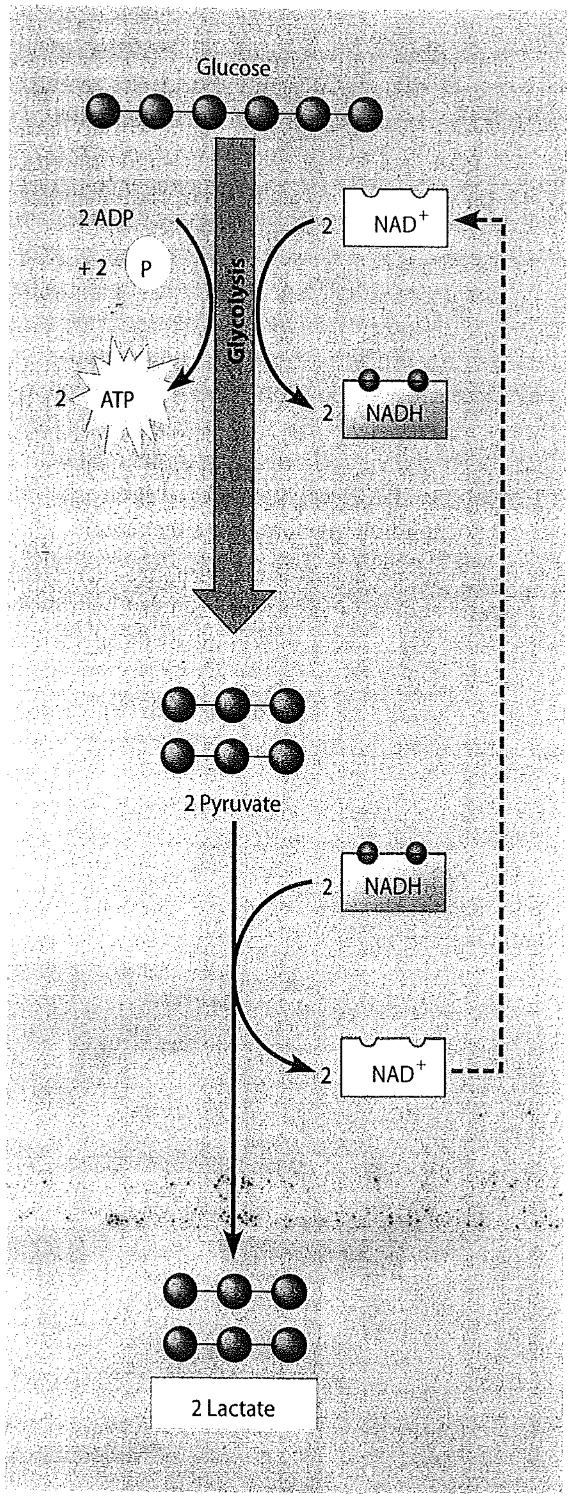
There is more to fermentation, however, than just glycolysis. To oxidize glucose in glycolysis, NAD^+ must be present as an electron acceptor. This is no problem under aerobic conditions, because the cell regenerates its pool of NAD^+ when NADH passes its electrons into the mitochondrion, to be transported to the electron transport chain. Fermentation provides an anaerobic path for recycling NADH back to NAD^+.

Lactic Acid Fermentation One common type of fermentation is called **lactic acid fermentation**. Your muscle cells and certain bacteria can regenerate NAD^+ by this process, as illustrated in **Figure 5.7**. You can see that NADH is oxidized to NAD^+ as pyruvate is reduced to lactate (the ionized form of lactic acid). Muscle cells can switch to lactic acid fermentation when the need for ATP outpaces the delivery of O_2 via the bloodstream. The lactate that builds up in muscle cells during strenuous exercise was previously thought to cause muscle fatigue and pain, but research now indicates that other factors are to blame. In any case, the lactate is carried in the blood to the liver, where it is converted back to pyruvate and oxidized in the mitochondria of liver cells.

The dairy industry uses lactic acid fermentation by bacteria to make cheese and yogurt. Other types of microbial fermentation turn soybeans into soy sauce and cabbage into sauerkraut.

? A glucose-fed yeast cell is moved from an aerobic environment to an anaerobic one. For the cell to continue generating ATP at the same rate, how would its rate of glucose consumption need to change?

The cell would have to consume glucose at a rate about 16 times the consumption rate in the aerobic environment (2 ATP per glucose molecule is made by fermentation versus 32 ATP by cellular respiration).



▲ **Figure 5.7** Lactic acid fermentation: NAD^+ is regenerated as pyruvate is reduced to lactate.

Connections Between Metabolic Pathways

5.8 Cells use many kinds of organic molecules as fuel for cellular respiration

Throughout this chapter, we have spoken of glucose as the fuel for cellular respiration. But free glucose molecules are not common in your diet. You obtain most of your calories as carbohydrates (such as sucrose and other disaccharide sugars and starch, a polysaccharide), fats, and proteins. You consume all three of these classes of organic molecules when you eat a handful of peanuts, for instance.

Figure 5.8 illustrates how a cell can use these three types of molecules to make ATP. A wide range of carbohydrates can be funneled into glycolysis, as indicated by the arrows on the far left of the diagram. For example, enzymes in your digestive tract hydrolyze starch to glucose, which is then broken down by glycolysis and the citric acid cycle. Similarly, glycogen, the polysaccharide stored in your liver and muscle cells, can be hydrolyzed to glucose to serve as fuel between meals.

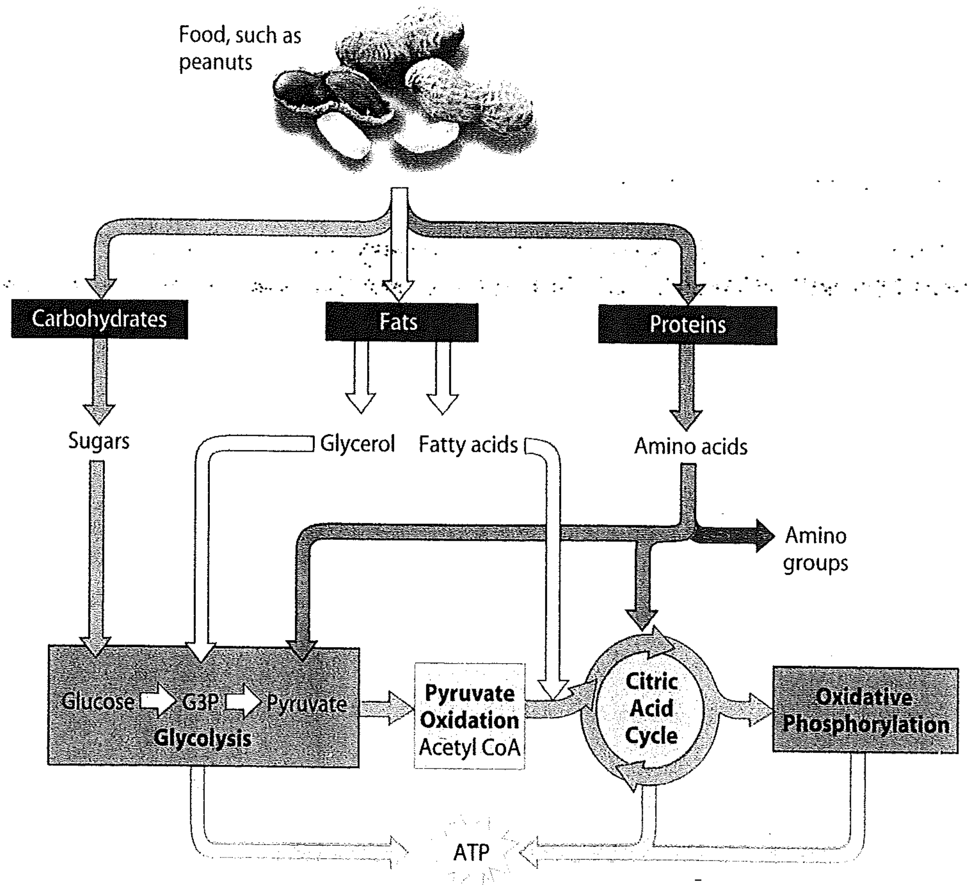
Fats make excellent cellular fuel because they contain many hydrogen atoms and thus many energy-rich electrons. As the diagram shows (tan arrows), a cell first hydrolyzes fats to glycerol and fatty acids. It then converts the glycerol to glyceraldehyde 3-phosphate (G3P), one of the intermediates in glycolysis. The fatty acids are broken into two-carbon fragments that enter the citric acid cycle as acetyl CoA.

A gram of fat yields more than twice as much ATP as a gram of carbohydrate. Because so many calories are stockpiled in each gram of fat, you must expend a large amount of energy to burn fat stored in your body. This helps explain why it is so difficult for a dieter to lose excess fat.

Proteins (purple arrows in Figure 5.8) can also be used for fuel, although your body preferentially burns sugars and fats first. To be oxidized as fuel, proteins must first be digested to their constituent amino acids. Typically, a cell will use most of these amino acids to make its own proteins. Enzymes can convert excess amino acids to intermediates of glycolysis or the citric acid cycle, and their energy is then harvested by cellular respiration. During the conversion, the amino groups are stripped off and later disposed of in urine.

? Animals store most of their energy reserves as fats, not as polysaccharides. What is the advantage of this mode of storage for an animal?

Most animals are mobile and benefit from a compact and concentrated form of energy storage. Also, because fats are hydrophobic, they can be stored without extra water associated with them.



▲ **Figure 5.8** Pathways that break down various food molecules

5.9 Food molecules provide raw materials for biosynthesis

Not all food molecules are destined to be oxidized as fuel for making ATP. Food also provides the raw materials your cells use for biosynthesis—the production of organic molecules using energy-requiring metabolic pathways. A cell must be able to make its own molecules to build its structures and perform its functions. Some raw materials, such as amino acids, can be incorporated directly into your macromolecules. However, your cells also need to make molecules that are not present in your food. Indeed, glycolysis and the citric acid cycle function as metabolic interchanges that enable your cells to convert some kinds of molecules to others as you need them.

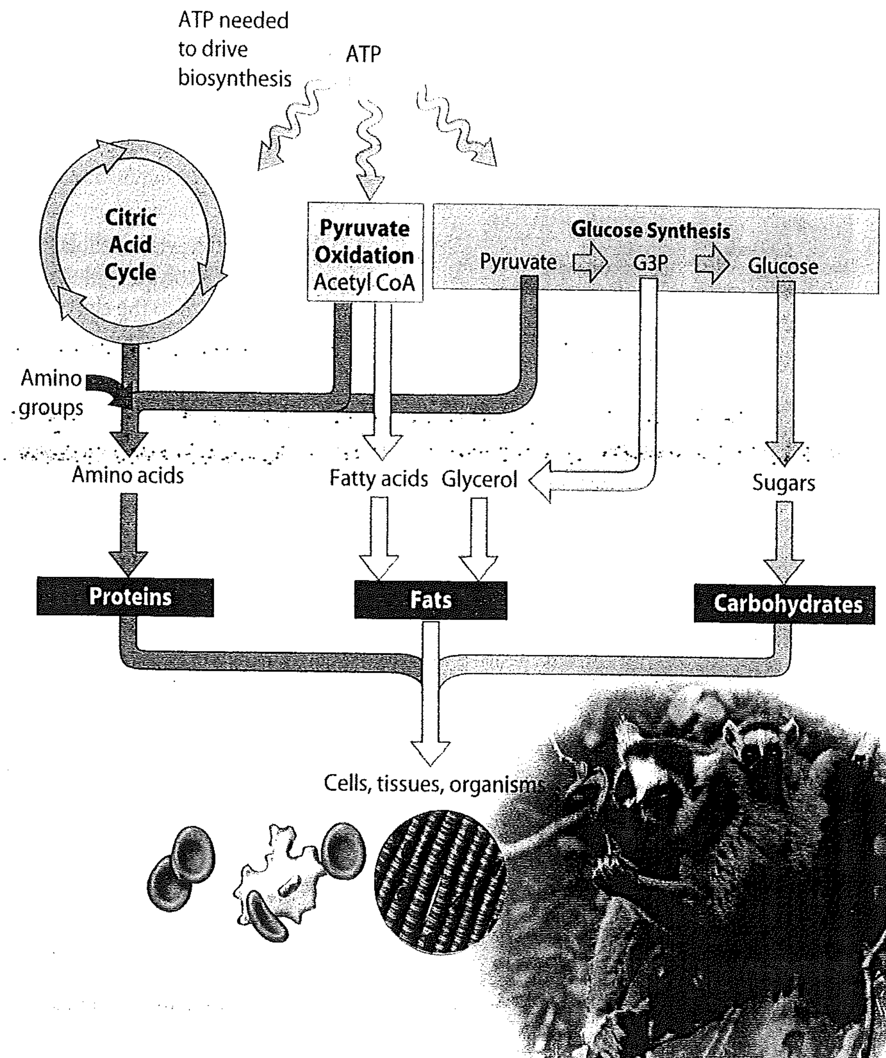
Figure 5.9 outlines the pathways by which your cells can make three classes of organic molecules using some of the intermediate molecules of glycolysis and the citric acid cycle. By comparing Figures 5.8 and 5.9, you can see clear connections between the energy-harvesting processes of cellular respiration and the biosynthetic pathways used to construct the organic molecules of the cell.

Basic principles of supply and demand regulate these pathways. If there is an excess of a certain amino acid, for example, the pathway that synthesizes it is switched off. The most common mechanism for this control is feedback inhibition: The end product inhibits an enzyme that catalyzes an early step in the pathway. Feedback inhibition also controls cellular respiration. If ATP accumulates in a cell, it inhibits an early enzyme in glycolysis, slowing down respiration and conserving resources. On the other hand, the same enzyme is activated by a buildup of ADP in the cell, signaling the need for more energy.

The cells of all living organisms—including those of the lemurs shown in Figure 5.9 and the plants they eat—have the ability to harvest energy from the breakdown of organic molecules. When the process is cellular respiration, the atoms of the starting materials end up in carbon dioxide and water. In contrast, the ability to make organic molecules from carbon dioxide and water is not universal. Animal cells lack this ability, but plant cells can actually produce organic molecules from inorganic ones using the energy of sunlight. This process, photosynthesis, is the subject of Chapter 6.

? Explain how someone can gain weight and store fat even when on a low-fat diet. (*Hint:* Look for G3P and acetyl CoA in Figures 5.8 and 5.9.)

If caloric intake is excessive, body cells use metabolic pathways to convert the excess to fat. The glycerol and fatty acids of fats are made from G3P and acetyl CoA, respectively, both produced from the oxidation of carbohydrates.



▲ **Figure 5.9** Biosynthesis of large organic molecules from intermediates of cellular respiration

CHAPTER 5 REVIEW

Reviewing the Concepts

Cellular Respiration: Aerobic Harvesting of Energy (5.1–5.4)

5.1 Photosynthesis and cellular respiration provide energy for life. Photosynthesis uses solar energy to produce glucose and O_2 from CO_2 and H_2O. In cellular respiration, O_2 is consumed during the breakdown of glucose to CO_2 and H_2O, and energy is released.

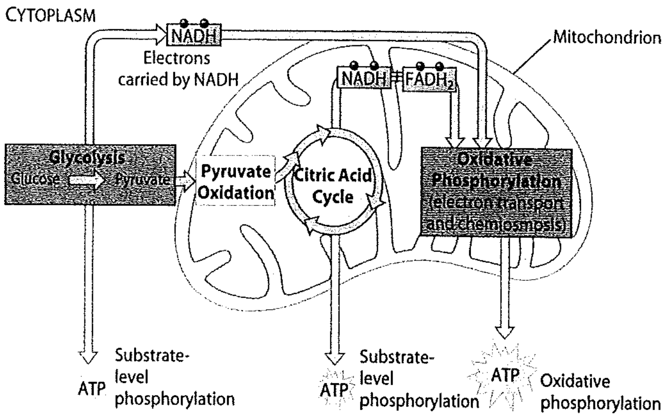
5.2 Breathing supplies O_2 for use in cellular respiration and removes CO_2.

5.3 Cellular respiration banks energy in ATP molecules. The summary equation for cellular respiration is $C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O$ + Energy (ATP + Heat).

5.4 The human body uses energy from ATP for all its activities.

Stages of Cellular Respiration (5.5–5.6)

5.5 Overview: Cellular respiration occurs in three main stages.



5.6 Review: Each molecule of glucose yields many molecules of ATP. Substrate-level phosphorylation and oxidative phosphorylation produce up to 32 ATP molecules for every glucose molecule oxidized in cellular respiration.

Fermentation: Anaerobic Harvesting of Energy (5.7)

5.7 Fermentation enables cells to produce ATP without oxygen. Under anaerobic conditions, muscle cells, yeasts, and certain bacteria produce ATP by glycolysis. NAD^+ is recycled from NADH as pyruvate is reduced to lactate (lactic acid fermentation).

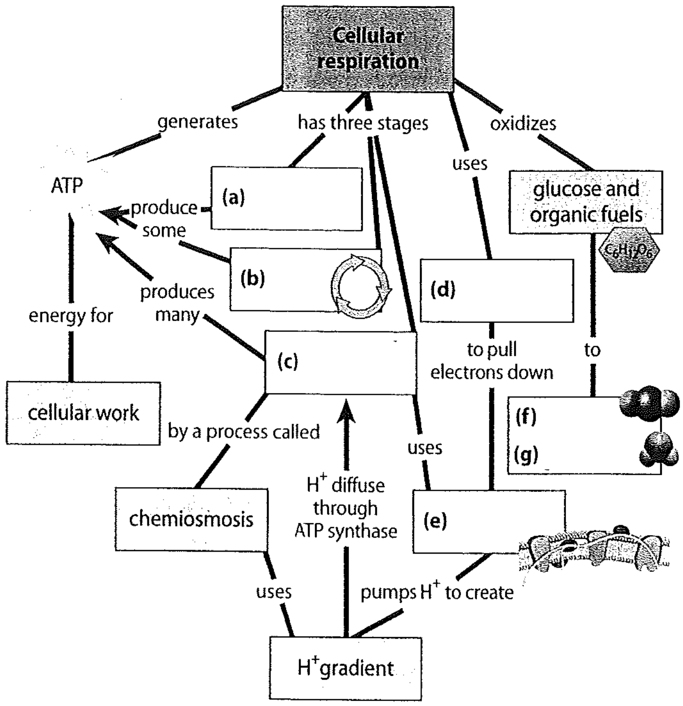
Connections Between Metabolic Pathways (5.8–5.9)

5.8 Cells use many kinds of organic molecules as fuel for cellular respiration. Carbohydrates, fats, and proteins can all fuel cellular respiration.

5.9 Food molecules provide raw materials for biosynthesis. Cells use intermediates from cellular respiration and ATP for biosynthesis of other organic molecules. Metabolic pathways are often regulated by feedback inhibition.

Connecting the Concepts

1. Fill in the blanks in this summary map to help you review the key concepts of cellular respiration.



Testing Your Knowledge

Multiple Choice

2. What is the role of oxygen in cellular respiration?
   a. It is reduced in glycolysis as glucose is oxidized.
   b. It provides electrons to the electron transport chain.
   c. It combines with the carbon removed during the citric acid cycle to form CO_2.
   d. It is required for the production of heat and light.
   e. It accepts electrons from the electron transport chain.

3. When the poison cyanide blocks the electron transport chain, glycolysis and the citric acid cycle soon grind to a halt as well. Why do you think they stop?
   a. They both run out of ATP.
   b. Unused O_2 interferes with cellular respiration.
   c. They run out of NAD^+ and FAD.
   d. Electrons are no longer available.
   e. They run out of ADP.

4. A biochemist wanted to study how various substances were used in cellular respiration. In one experiment, he allowed a mouse to breathe air containing O_2 "labeled" by a particular isotope. In the mouse, the labeled oxygen first showed up in
   a. ATP.
   b. glucose ($C_6H_{12}O_6$).
   c. NADH.
   d. CO_2.
   e. H_2O.

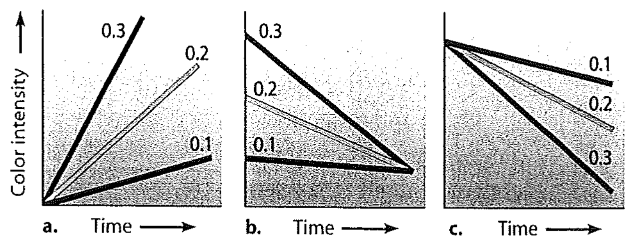
5. In glycolysis, ______ is oxidized and ______ is reduced.
   a. NAD^+ . . . glucose
   b. glucose . . . oxygen
   c. ATP . . . ADP
   d. glucose . . . NAD^+
   e. ADP . . . ATP
6. Which of the following is the most immediate source of energy for making most of the ATP in your cells?
   a. the reduction of oxygen
   b. the transfer of P from intermediate substrates to ADP
   c. the movement of H^+ across a membrane down its concentration gradient
   d. the splitting of glucose into two molecules of pyruvate
   e. electrons moving through the electron transport chain
7. In which of the following is the first molecule becoming reduced to the second molecule?
   a. pyruvate $\longrightarrow$ acetyl CoA
   b. pyruvate $\longrightarrow$ lactate
   c. glucose pyruvate
   d. $NADH + H^+ \longrightarrow NAD^+ + 2\,H$
   e. $C_6H_{12}O_6 \longrightarrow 6\,CO_2$
8. Which of the following is a true distinction between cellular respiration and fermentation?
   a. NADH is oxidized by the electron transport chain in respiration only.
   b. Only respiration oxidizes glucose.
   c. Fermentation is an example of an endergonic reaction; cellular respiration is an exergonic reaction.
   d. Substrate-level phosphorylation is unique to fermentation; cellular respiration uses oxidative phosphorylation.
   e. Fermentation is the metabolic pathway found in prokaryotes; cellular respiration is unique to eukaryotes.

Describing, Comparing, and Explaining

9. Which of the three stages of cellular respiration is considered the most ancient? Explain your answer.
10. Explain in terms of cellular respiration why you need oxygen and why you exhale carbon dioxide.
11. Compare and contrast fermentation as it occurs in your muscle cells and as it occurs in yeast cells.
12. Explain how your body can convert excess carbohydrates in the diet to fats. Can excess carbohydrates be converted to protein? What else must be supplied?

Applying the Concepts

13. An average adult human requires 2,200 kcal of energy per day. Suppose your diet provides an average of 2,300 kcal per day. How many hours per week would you have to walk to burn off the extra calories? Swim? Run? (See Figure 5.4.)
14. Your body makes NAD^+ and FAD from two B vitamins, niacin and riboflavin. The Recommended Dietary Allowance for niacin is 20 mg and for riboflavin, 1.7 mg. These amounts are thousands of times less than the amount of glucose your body needs each day to fuel its energy needs. Why is the daily requirement for these vitamins so small?
15. In a detail of the citric acid cycle, an enzyme converts succinate to a compound called fumarate, with the release of H^+. You are studying this reaction using a suspension of bean cell mitochondria and a blue dye that loses its color as it takes up H^+. You know that the higher the concentration of succinate, the more rapid the decolorization of the dye. You set up reaction mixtures with mitochondria, dye, and three different concentrations of succinate (0.1 mg/L, 0.2 mg/L, and 0.3 mg/L). Which of the following graphs represents the results you would expect, and why?



16. ATP synthase enzymes are found in the prokaryotic plasma membrane and in the inner membrane of a mitochondrion. What does this suggest about the developmental relationship of this eukaryotic organelle to prokaryotes?

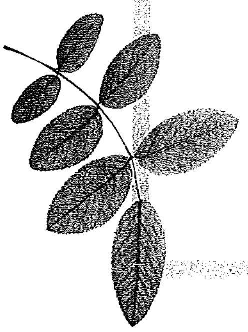
Answers to all questions can be found in Appendix 1.

CHAPTER

6

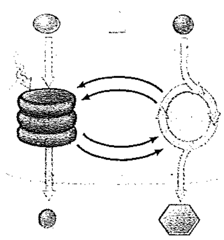
Photosynthesis: *Using Light to Make Food*

BIG IDEAS



An Overview of Photosynthesis
(6.1–6.4)

Plants and other photoautotrophs use the energy of sunlight to convert CO_2 and H_2O to sugar and O_2.



Photosynthesis Reviewed and Extended
(6.5–6.6)

Photosynthesis provides the energy and building material for ecosystems. It also affects global climate and the ozone layer.

An Overview of Photosynthesis

6.1 Autotrophs are the producers of the biosphere

Plants are **autotrophs** (meaning "self-feeders" in Greek) in that they make their own food and thus sustain themselves without consuming organic molecules derived from any other organisms. Plant cells capture light energy that has traveled 150 million kilometers from the sun and convert it to chemical energy. Because they use the energy of light, plants are specifically called *photoautotrophs*. Through the process of **photosynthesis**, plants convert CO_2 and H_2O to their own organic molecules and release O_2 as a by-product. Photoautotrophs are the ultimate source of organic molecules for almost all other organisms. They are often referred to as the producers of the biosphere because they produce its food supply. Producers feed the consumers of the biosphere—the **heterotrophs** that consume other plants or animals or decompose organic material (*hetero* means "other").

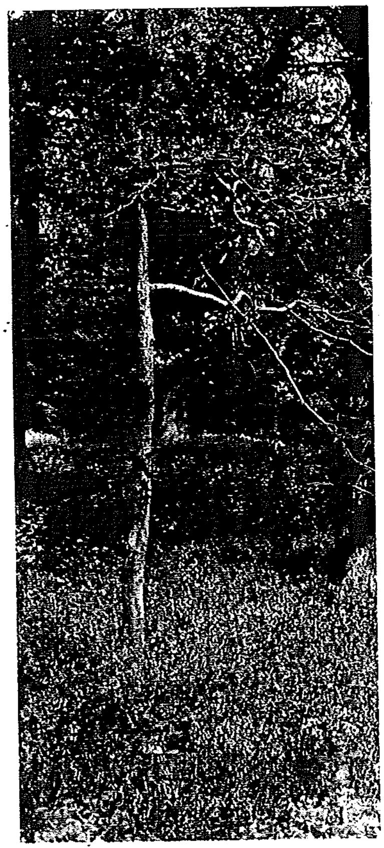
The photographs on this page illustrate some of the diversity among photoautotrophs. On land, plants, such as those in the forest scene in **Figure 6.1A**, are the predominant producers. In aquatic environments, there are several types of photoautotrophs. **Figure 6.1B** is a micrograph of unicellular photosynthetic protists. **Figure 6.1C** shows kelp, a large alga that forms extensive underwater "forests" off the coast of California. **Figure 6.1D** is a micrograph of cyanobacteria, abundant and important producers in freshwater and marine ecosystems.

In this chapter, we focus on photosynthesis in plants, which takes place in chloroplasts. The remarkable ability to harness light energy and use it to drive the synthesis of organic compounds emerges from the structural organization of these organelles: Photosynthetic pigments, enzymes, and other molecules are grouped together in membranes, allowing the sequences of reactions to be carried out efficiently. The process of photosynthesis most likely originated in a group of bacteria that had infolded regions of the plasma membrane containing such clusters of enzymes and other molecules. In fact, according to the widely accepted theory of endosymbiosis, chloroplasts originated from a photosynthetic prokaryote that took up residence inside a eukaryotic cell.

Let's begin our study of photosynthesis with an overview of the location and structure of plant chloroplasts.

? What do "self-feeding" photoautotrophs require from the environment in order to make their own food?

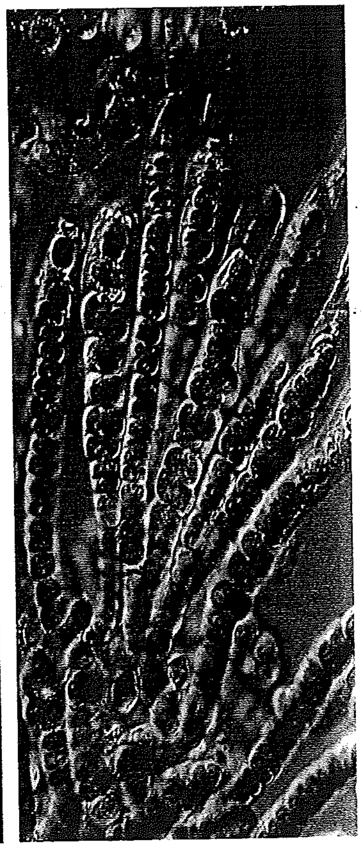
Light, carbon dioxide, and water. (Minerals are also required; you'll learn about the needs of plants later in this book.)



▲ **Figure 6.1A** Forest plants

▲ **Figure 6.1B** Photosynthetic protists

▲ **Figure 6.1C** Kelp, a multicellular alga



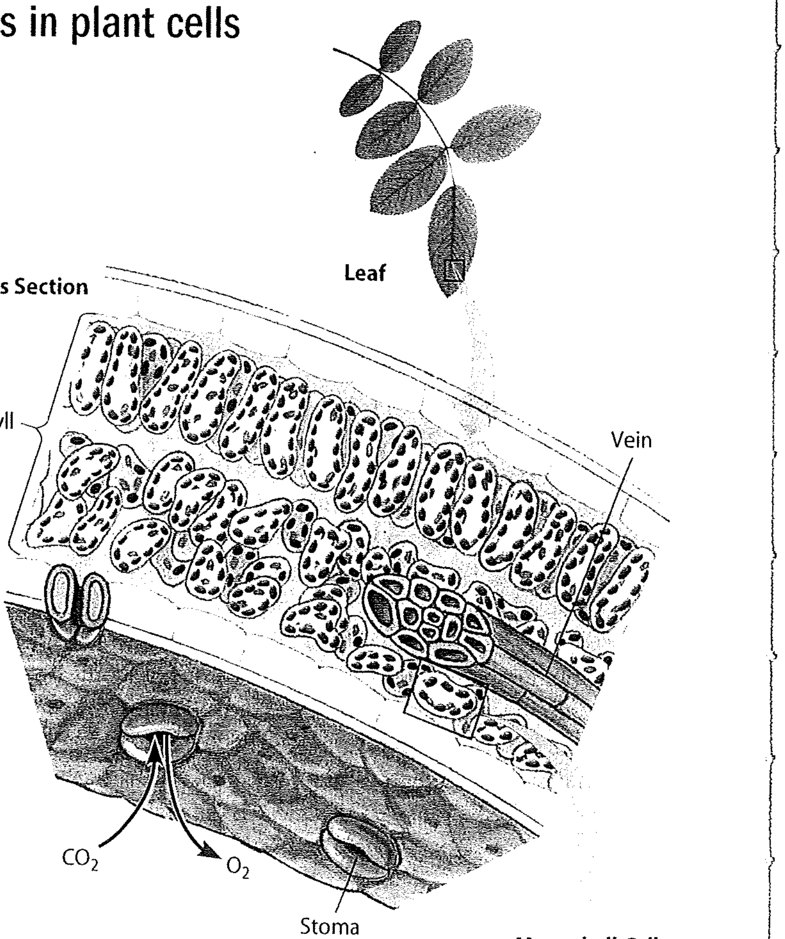
▲ **Figure 6.1D** Cyanobacteria (photosynthetic prokaryotes)

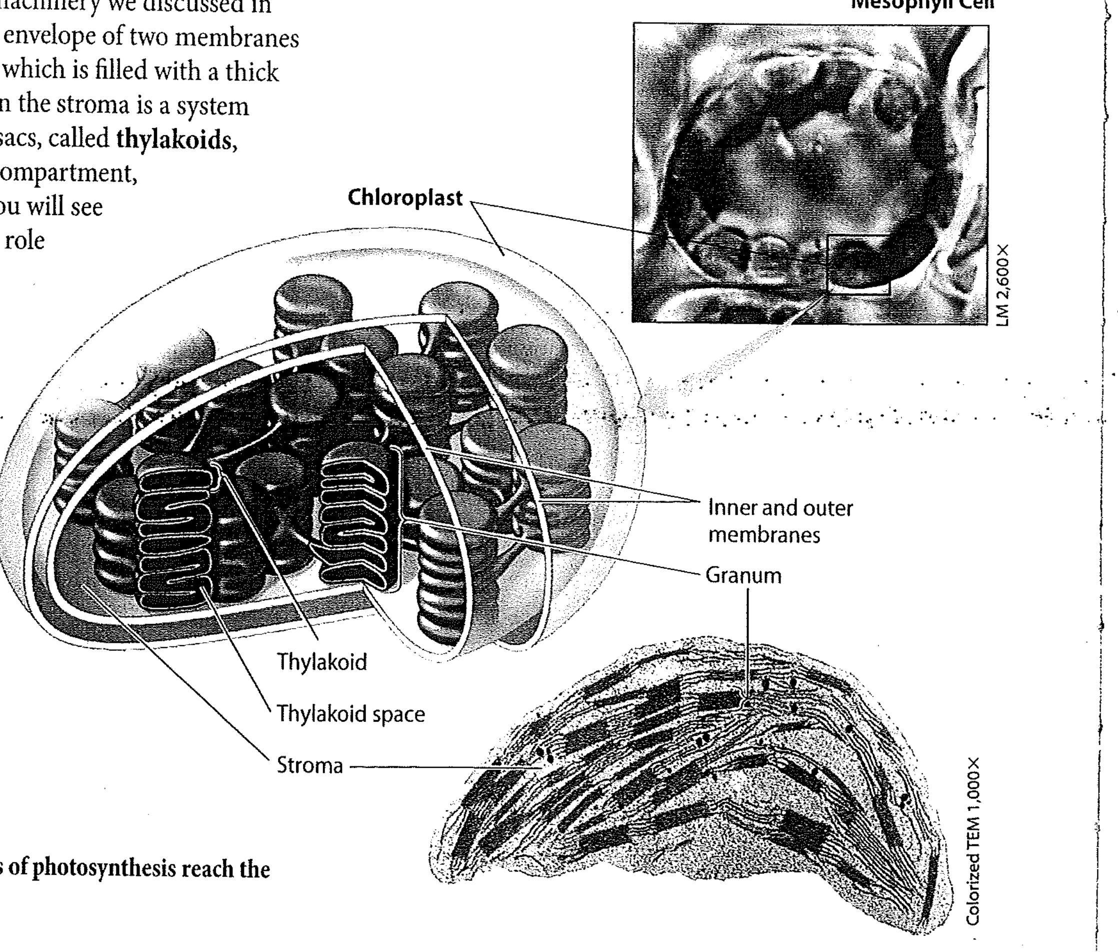
6.2 Photosynthesis occurs in chloroplasts in plant cells

All green parts of a plant have chloroplasts in their cells and can carry out photosynthesis. In most plants, however, the leaves have the most chloroplasts (about half a million in a square millimeter surface area of a leaf) and are the major sites of photosynthesis. Their green color comes from **chlorophyll**, a light-absorbing pigment in the chloroplasts that plays a central role in converting solar energy to chemical energy.

Figure 6.2 zooms in on a leaf to show the actual sites of photosynthesis. The leaf cross section shows a slice through a leaf. Chloroplasts are concentrated in the cells of the **mesophyll**, the green tissue in the interior of the leaf. Carbon dioxide enters the leaf, and oxygen exits, by way of tiny pores called **stomata** (singular, *stoma*, meaning "mouth"). Water absorbed by the roots is delivered to the leaves in veins. Leaves also use veins to export sugar to roots and other parts of the plant.

As you can see in the light micrograph of a single mesophyll cell, each cell has numerous chloroplasts. A typical mesophyll cell has about 30 to 40 chloroplasts. The bottom drawing and electron micrograph show the structures in a single chloroplast. Membranes in the chloroplast form the framework where many of the reactions of photosynthesis occur, just as mitochondrial membranes are the site for much of the energy-harvesting machinery we discussed in Chapter 5. In the chloroplast, an envelope of two membranes encloses an inner compartment, which is filled with a thick fluid called **stroma**. Suspended in the stroma is a system of interconnected membranous sacs, called **thylakoids**, which enclose another internal compartment, called the thylakoid space. (As you will see later, this thylakoid space plays a role analogous to the intermembrane space of a mitochondrion in the generation of ATP.) In many places, thylakoids are concentrated in stacks called **grana** (singular, *granum*). Built into the thylakoid membranes are the chlorophyll molecules that capture light energy. The thylakoid membranes also house much of the machinery that converts light energy to chemical energy, which is used in the stroma to make sugar.





▲ **Figure 6.2** Zooming in on the location and structure of chloroplasts

? How do the reactant molecules of photosynthesis reach the chloroplasts in leaves?

CO_2 enters leaves through stomata, and H_2O enters the roots and is carried to leaves through veins.

6.3 Photosynthesis is a redox process, as is cellular respiration

What actually happens when CO_2 and water are converted to sugar and O_2? Photosynthesis is a redox (oxidation-reduction) process, just as cellular respiration is. As indicated in the summary equation for photosynthesis **(Figure 6.3A)**, CO_2 becomes reduced to sugar as electrons, along with hydrogen ions (H^+) from water, are added to it. Meanwhile, water molecules are oxidized; that is, they lose electrons, along with hydrogen ions. Recall that oxidation and reduction always go hand in hand.

Now compare the food-producing equation for photosynthesis with the energy-releasing equation for cellular respiration that you learned about in Chapter 5 **(Figure 6.3B)**. Overall, cellular respiration harvests energy stored in a glucose molecule by oxidizing the sugar and reducing O_2 to H_2O. This process involves a number of energy-releasing redox reactions, with electrons losing potential energy as they "fall" down an electron transport chain to O_2. Along the way, the mitochondrion uses some of the energy to synthesize ATP.

In contrast, the food-producing redox reactions of photosynthesis require energy. The potential energy of electrons increases as they move from H_2O to CO_2 during photosynthesis. The light energy captured by chlorophyll molecules in the chloroplast provides this energy boost. Photosynthesis converts light energy to chemical energy and stores it in the chemical bonds of sugar molecules, which can provide energy for later use or raw materials for biosynthesis.

Becomes reduced

$$6\,CO_2 + 6\,H_2O \longrightarrow C_6H_{12}O_6 + 6\,O_2$$

Becomes oxidized

▲ **Figure 6.3A** Photosynthesis (uses light energy)

Becomes oxidized

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$$

Becomes reduced

▲ **Figure 6.3B** Cellular respiration (releases chemical energy)

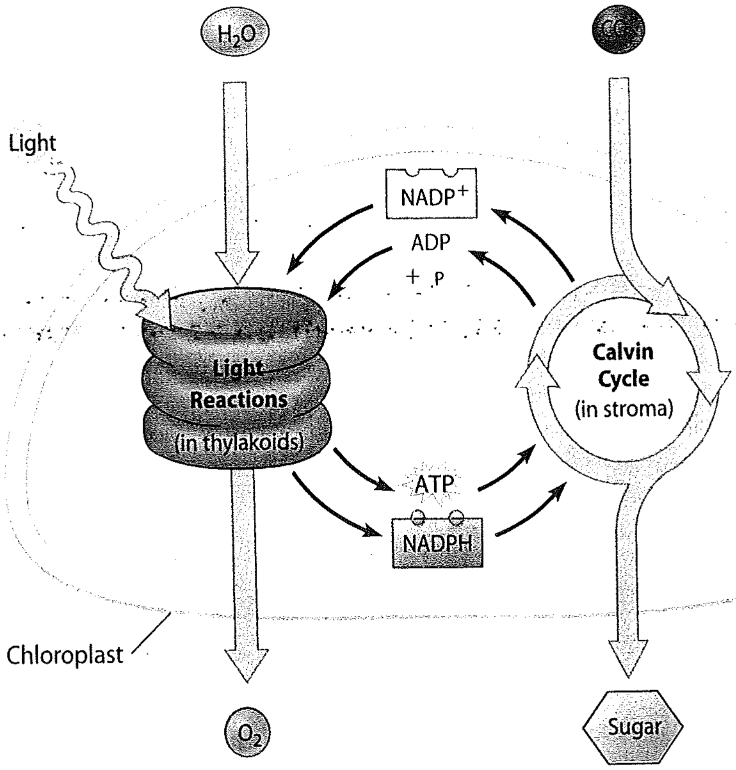
? Which redox process, photosynthesis or cellular respiration, is endergonic?

Photosynthesis.

6.4 Overview: The two stages of photosynthesis are linked by ATP and NADPH

The equation for photosynthesis is a simple summary of a very complex process. Actually, photosynthesis occurs in two stages, each with multiple steps. **Figure 6.4** shows the inputs and outputs of the two stages and how the stages are related.

The **light reactions** include the steps that convert light energy to chemical energy and release O_2. As shown in the figure, the light reactions occur in the thylakoid membranes. Water is split, providing a source of electrons and giving off O_2 as a by-product. Light energy absorbed by chlorophyll molecules built into the membranes is used to drive the transfer of electrons and H^+ from water to the electron acceptor **NADP$^+$**, reducing it to NADPH. This electron carrier is first cousin to NADH, which transports electrons in cellular respiration; the two differ only in the extra phosphate group in NADPH. NADPH temporarily stores electrons and hydrogen ions and provides "reducing power" to the Calvin cycle. The light reactions also generate ATP from ADP and a phosphate group.



▲ **Figure 6.4** An overview of the two stages of photosynthesis in a chloroplast

In summary, the light reactions absorb solar energy and convert it to chemical energy stored in both ATP and NADPH. Notice that these reactions produce no sugar; sugar is not made until the Calvin cycle, which is the second stage of photosynthesis.

The **Calvin cycle** occurs in the stroma of the chloroplast (see Figure 6.4). It is a cyclic series of reactions that assembles sugar molecules using CO_2 and the energy-rich products of the light reactions. The incorporation of carbon from CO_2 into organic compounds, shown in the figure as CO_2 entering the Calvin cycle, is called **carbon fixation**. After carbon fixation, enzymes of the cycle make sugars by further reducing the carbon compounds.

As the figure suggests, it is NADPH produced by the light reactions that provides the electrons for reducing carbon in the Calvin cycle. And ATP from the light reactions provides chemical energy that powers several of the steps of the Calvin cycle. The Calvin cycle is sometimes referred to as the dark reactions, or light-independent reactions, because none of the steps requires light directly. However, in most plants, the Calvin cycle occurs during daylight, when the light reactions power the cycle's sugar assembly line by supplying it with NADPH and ATP.

The word *photosynthesis* encapsulates the two stages. *Photo*, from the Greek word for "light," refers to the light reactions; *synthesis*, meaning "putting together," refers to sugar construction by the Calvin cycle. In the next several modules, we look at these two stages in more detail. But first, let's consider some of the properties of light, the energy source that powers photosynthesis.

? For chloroplasts to produce sugar from carbon dioxide in the dark, they would need to be supplied with _____ and _____.

ATP . . . NADPH

Photosynthesis Reviewed and Extended

6.5 Review: Photosynthesis uses light energy, carbon dioxide, and water to make organic molecules

Life on Earth is solar powered. As we have discussed, most of the living world depends on the food-making machinery of photosynthesis. **Figure 6.5** summarizes this vital process. The production of sugar from CO_2 is an emergent property that arises from the structure of a chloroplast—a structural arrangement that integrates the two stages of photosynthesis.

Starting on the left in the diagram, you see a summary of the light reactions, which occur in the thylakoid membranes. Two photosystems in the membranes capture solar energy, energizing electrons in chlorophyll molecules. Simultaneously, water is split, and O_2 is released. The photoexcited electrons are transferred through an electron transport chain, where energy is harvested to make ATP, and finally to $NADP^+$, reducing it to the high-energy compound NADPH.

The chloroplast's sugar factory is the Calvin cycle, the second stage of photosynthesis. In the stroma, the enzyme rubisco combines CO_2 with RuBP. ATP and NADPH are used to reduce 3-PGA to G3P. Sugar molecules made from G3P serve as a plant's own food supply.

About 50% of the carbohydrate made by photosynthesis is consumed as fuel for cellular respiration in the mitochondria of plant cells. Sugars also serve as starting material for making other organic molecules, such as a plant's proteins and lipids. Many glucose molecules are linked together to make cellulose, the main component of cell walls. Cellulose is the most abundant organic molecule in a plant—and probably on the surface of the planet. Most plants make much more food each day than they need. They store the excess in roots, tubers, seeds, and fruits.

Plants (and other photosynthesizers) not only feed themselves but also are the ultimate source of food for virtually all other organisms. Humans and other animals make none of their own food and are totally dependent on the organic matter made by photosynthesizers. Even the energy we acquire when we eat meat was originally captured by photosynthesis. The energy in a hamburger, for instance, came from sunlight that was originally converted to a chemical form in the grasses eaten by cattle.

The collective productivity of the tiny chloroplasts is truly amazing: Photosynthesis makes an estimated 160 billion metric tons of carbohydrate per year (about 176 billion tons). That's equivalent in mass to a stack of about 100 trillion copies of this textbook. No other chemical process on Earth can match the output of photosynthesis.

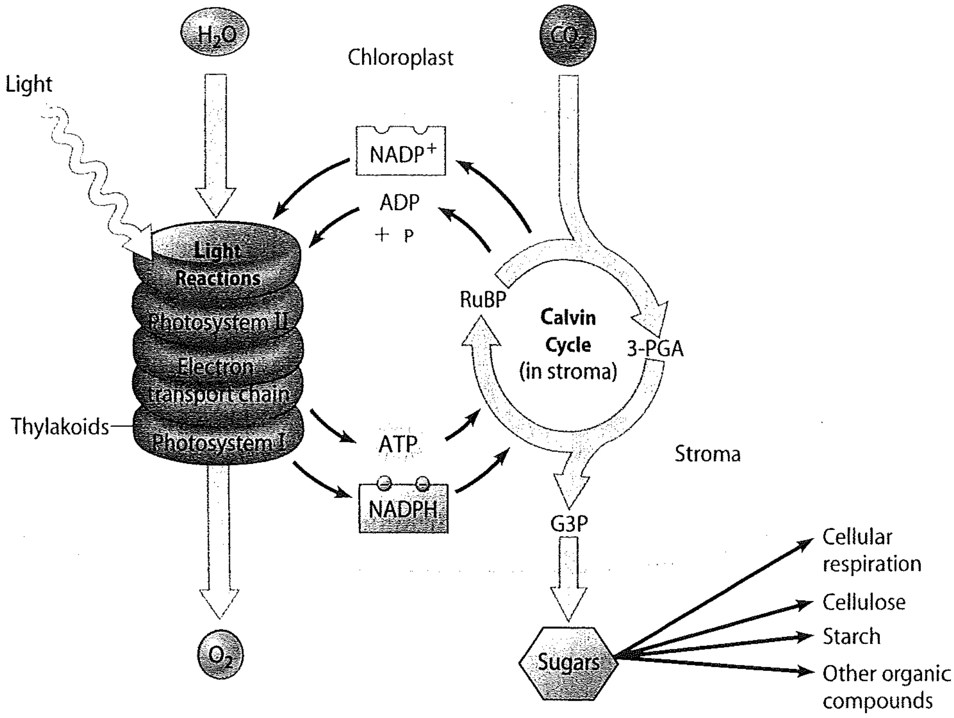
This review of photosynthesis is an appropriate place to reflect on the metabolic ground we have covered in this chapter and the previous one. In Chapter 5, we saw that virtually all organisms, plants included, use cellular respiration to obtain the energy they need from fuel molecules such as glucose. We followed the chemical pathways of glycolysis and the citric acid cycle, which oxidize glucose and release energy from it. We have now come full circle, seeing how plants trap sunlight energy and use it to reduce carbon dioxide to make glucose.

In tracing glucose synthesis and its breakdown, we have also seen that cells use several of the same mechanisms—electron transport, redox reactions, and chemiosmosis—in energy storage (photosynthesis) and energy harvest (cellular respiration).

? Explain this statement: No process is more important than photosynthesis to the welfare of life on Earth.

Photosynthesis is the ultimate source of the food for almost all organisms and the oxygen they need for cellular respiration.

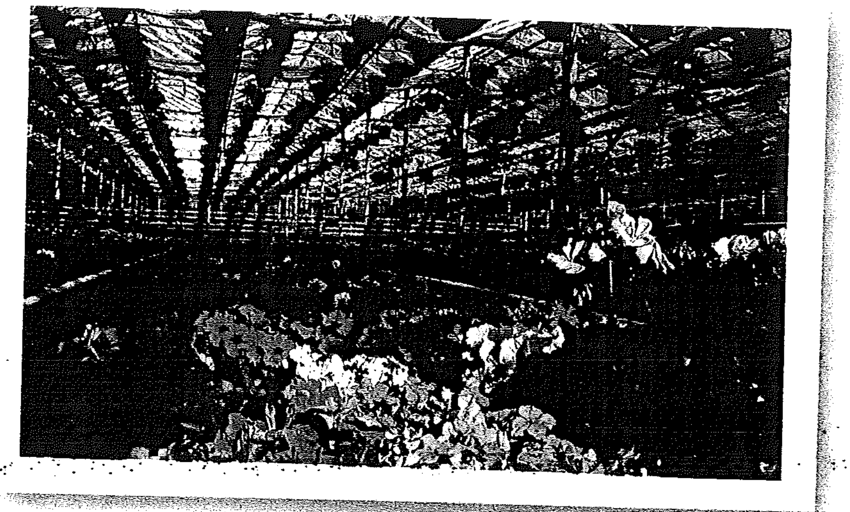
▶ **Figure 6.5** A summary of photosynthesis



CONNECTION 6.6 Photosynthesis may moderate global climate change

The greenhouse in **Figure 6.6A** is used to grow plants when the weather outside is too cold. The glass or plastic walls of a greenhouse allow solar radiation to pass through. The sunlight heats the soil, which in turn warms the air. The walls trap the warm air, raising the temperature inside.

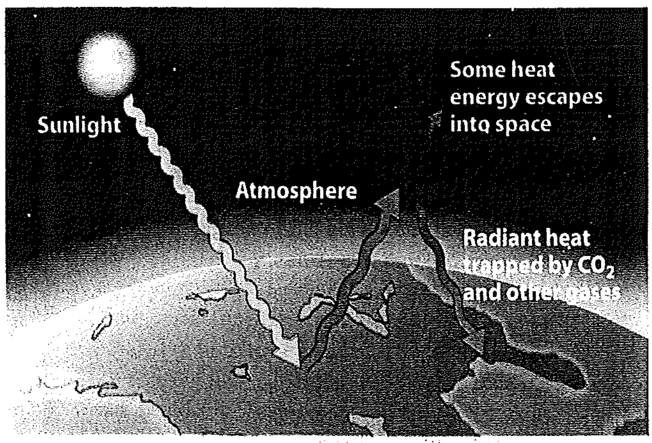
An analogous process, called the **greenhouse effect**, operates on a global scale (**Figure 6.6B**). Solar radiation reaching Earth's atmosphere includes ultraviolet radiation and visible light. The ozone layer filters out most of the damaging UV radiation. Visible light passes through and is absorbed by the planet's surface, warming it. Heat radiating from the warmed planet is absorbed by gases in the atmosphere, which then reflect some of the heat back to Earth. This natural heating effect is highly beneficial. Without it, Earth would be much colder, and most life as we know it could not exist.



▲ **Figure 6.6A** Plants growing in a greenhouse

The gases in the atmosphere that absorb heat radiation are called greenhouse gases. Some occur naturally, such as water vapor, carbon dioxide, and methane, while others are synthetic, such as chlorofluorocarbons. Human activities add to the levels of these greenhouse gases.

Carbon dioxide is one of the most important greenhouse gases. You have just learned that CO_2 is a raw material for photosynthesis and a waste product of cellular respiration. These two processes, taking place in microscopic chloroplasts and



▲ **Figure 6.6B** CO_2 in the atmosphere and the greenhouse effect

mitochondria, keep carbon cycling between CO_2 and more complex organic compounds on a global scale. Photosynthetic organisms absorb billions of tons of CO_2 each year. Most of that fixed carbon returns to the atmosphere via cellular respiration, the action of decomposers, and fires. But much of it remains locked in large tracts of forests and undecomposed organisms. And large amounts of carbon are in long-term storage in fossil fuels buried deep under Earth's surface.

Since 1850, the start of the Industrial Revolution, the atmospheric concentration of CO_2 has increased about 40%, mostly due to the combustion of fossil fuels, such as coal, oil, and gasoline. Increasing concentrations of greenhouse gases have been linked to **global climate change**, of which the major aspect is *global warming*. The predicted consequences of this slow but steady increase in average global temperature include melting of polar ice, rising sea levels, extreme weather patterns, droughts, increased extinction rates, and the spread of tropical diseases. Indeed, many of these effects are already being documented.

Unfortunately, the rise in atmospheric CO_2 levels during the last century coincided with widespread deforestation, which aggravated the global warming problem by reducing an effective CO_2 sink. As forests are cleared for lumber or agriculture, and as population growth increases the demand for fossil fuels, CO_2 levels will continue to rise.

Can photosynthesis offset this increase in atmospheric CO_2? Certainly, slowing the destruction of our forests will sustain their photosynthetic and carbon-storing contributions. Taking a lesson from plants, we can explore technologies that utilize solar energy for some of our energy needs. And as you read in the chapter introduction, biofuels hold out the promise of a renewable fuel source. As the plants or algae used for biofuels grow, their photosynthesis removes CO_2 from the atmosphere. The burning of these fuels releases CO_2 to the atmosphere, just as fossils fuels do. A key difference, however, is that fossil fuels come from the remains of ancient organisms, and their burning releases CO_2 that had been removed from the atmosphere by photosynthesis over the course of hundreds of millions of years. Growing and using alternative fuels could keep the cycle of CO_2 removal in photosynthesis balanced with CO_2 release in fuel burning.

? Explain the greenhouse effect.

Sunlight warms Earth's surface, which radiates heat to the atmosphere. CO_2 and other greenhouse gases absorb and radiate some heat back to Earth.

CHAPTER 6 REVIEW

Reviewing the Concepts

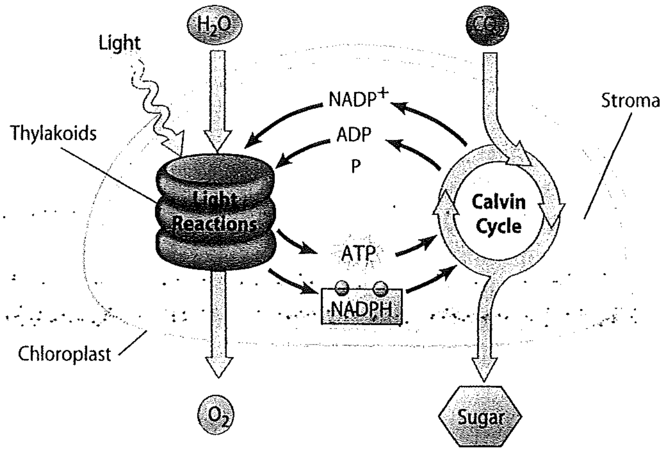
An Overview of Photosynthesis (6.1–6.4)

6.1 Autotrophs are the producers of the biosphere. Plants, algae, and some protists and bacteria are photoautotrophs, the producers of food consumed by virtually all heterotrophic organisms.

6.2 Photosynthesis occurs in chloroplasts in plant cells. Chloroplasts are surrounded by a double membrane and contain stacks of thylakoids and a thick fluid called stroma.

6.3 Photosynthesis is a redox process, as is cellular respiration. In photosynthesis, H_2O is oxidized and CO_2 is reduced.

6.4 Overview: The two stages of photosynthesis are linked by ATP and NADPH. The light reactions occur in the thylakoids, producing ATP and NADPH for the Calvin cycle, which takes place in the stroma.



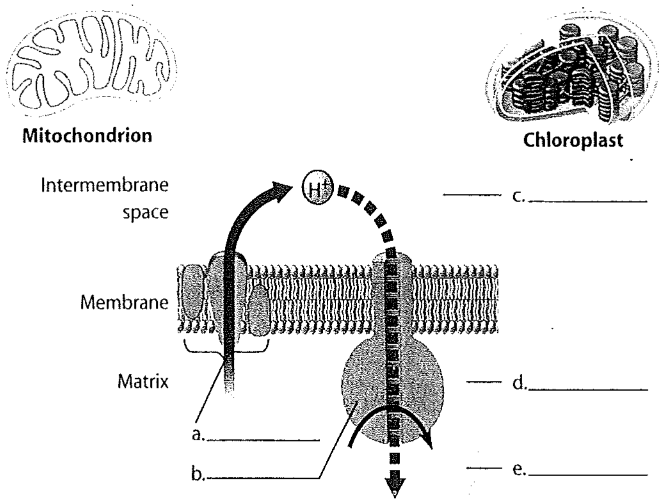
Photosynthesis Reviewed and Extended (6.5–6.6)

6.5 Review: Photosynthesis uses light energy, carbon dioxide, and water to make organic molecules.

6.6 Photosynthesis may moderate global climate change. Reducing deforestation and fossil fuel use and growing biofuel crops, which remove CO_2 from the atmosphere, may help moderate the global warming caused by increasing CO_2 levels.

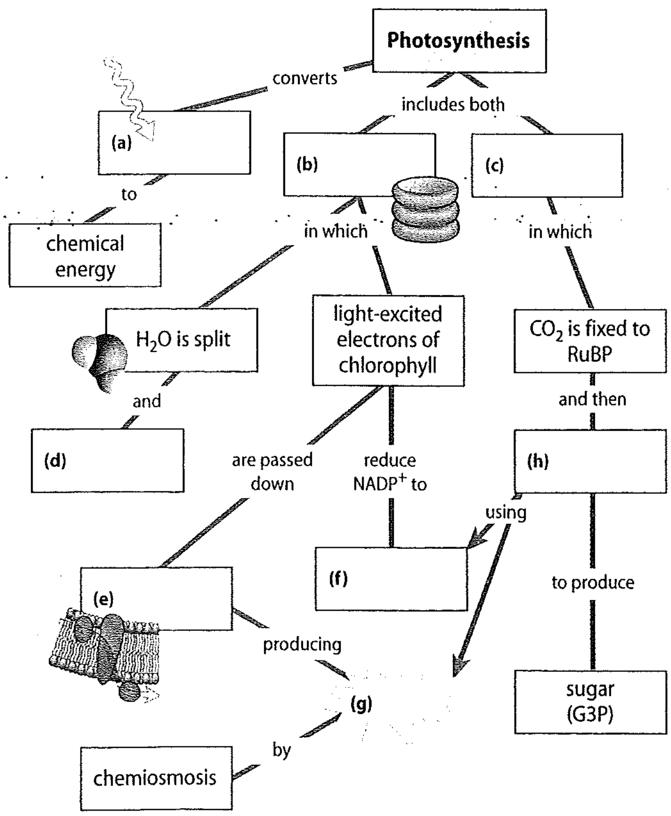
Connecting the Concepts

1. The following diagram compares the chemiosmotic synthesis of ATP in mitochondria and chloroplasts. Fill in the blanks, which label the molecules shared by both processes and the regions in the chloroplast. Then, for both organelles, indicate which side of the membrane has the higher H^+ concentration.



2. Continue your comparison of chemiosmosis and electron transport in mitochondria and chloroplasts. In each case,
   a. where do the electrons come from?
   b. how do the electrons get their high potential energy?
   c. what picks up the electrons at the end of the chain?
   d. how is the energy given up by the electrons used?

3. Complete this summary map of photosynthesis.



Testing Your Knowledge

Multiple Choice

4. In photosynthesis, ______ is oxidized and ______ is reduced.
   a. glucose . . . oxygen
   b. carbon dioxide . . . water
   c. water . . . carbon dioxide
   d. glucose . . . carbon dioxide
   e. water . . . oxygen

5. Which of the following are produced by reactions that take place in the thylakoids and consumed by reactions in the stroma?
   a. CO_2 and H_2O
   b. $NADP^+$ and ADP
   c. ATP and NADPH
   d. ATP, NADPH, and CO_2
   e. O_2 and ATP

6. When light strikes chlorophyll molecules in the reaction-center complex, they lose electrons, which are ultimately replaced by
   a. splitting water.
   b. breaking down ATP.
   c. oxidizing NADPH.
   d. fixing carbon.
   e. oxidizing glucose.

7. The reactions of the Calvin cycle are not directly dependent on light, but they usually do not occur at night. Why? (*Explain*.)
   a. It is often too cold at night for these reactions to take place.
   b. Carbon dioxide concentrations decrease at night.
   c. The Calvin cycle depends on products of the light reactions.
   d. Plants usually close their stomata at night.
   e. Most plants do not make four-carbon compounds, which they would need for the Calvin cycle at night.

8. How many "turns" of the Calvin cycle are required to produce one molecule of glucose? (Assume one CO_2 is fixed in each turn of the cycle.)
   a. 1
   b. 2
   c. 3
   d. 6
   e. 12

9. Which of the following does *not* occur during the Calvin cycle?
   a. carbon fixation
   b. oxidation of NADPH
   c. consumption of ATP
   d. regeneration of RuBP, the CO_2 acceptor
   e. release of oxygen

10. Why is it difficult for most plants to carry out photosynthesis in very hot, dry environments such as deserts?
    a. The light is too intense and destroys the pigment molecules.
    b. The closing of stomata keeps CO_2 from entering and O_2 from leaving the plant.
    c. They must rely on photorespiration to make ATP.
    d. Global warming is intensified in a desert environment.
    e. CO_2 builds up in the leaves, blocking carbon fixation.

11. How is photosynthesis similar in C_4 plants and CAM plants?
    a. In both cases, the light reactions and the Calvin cycle are separated in both time and location.
    b. Both types of plants make sugar without the Calvin cycle.
    c. In both cases, rubisco is not used to fix carbon initially.
    d. Both types of plants make most of their sugar in the dark.
    e. In both cases, thylakoids are not involved in photosynthesis.

Describing, Comparing, and Explaining

12. What are the major inputs and outputs of the two stages of photosynthesis?
13. Explain why a poison that inhibits an enzyme of the Calvin cycle will also inhibit the light reactions.
14. What do plants do with the sugar they produce in photosynthesis?

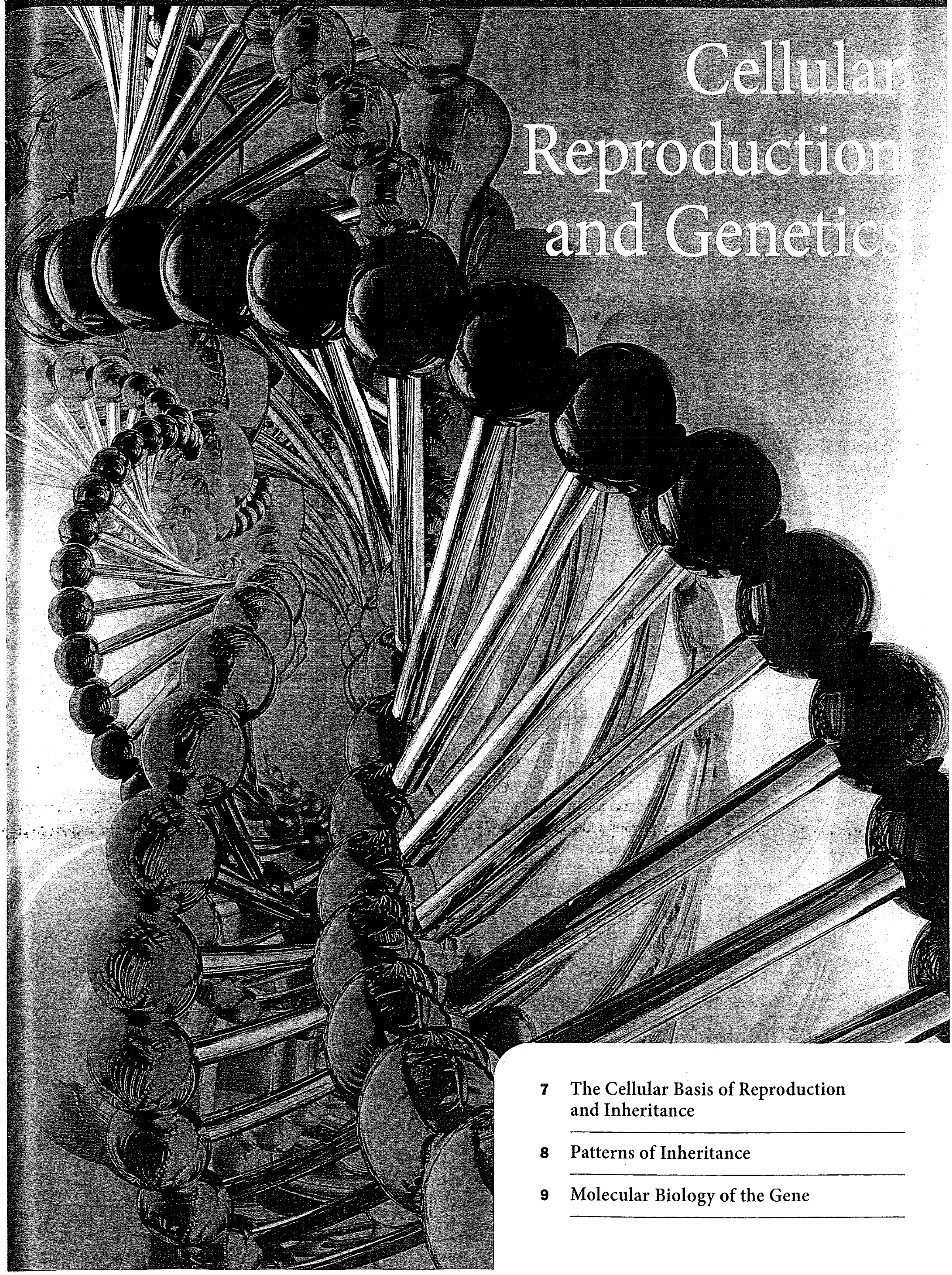
Applying the Concepts

15. Most experts agree that global warming is already occurring and will increase rapidly in this century. Many countries have made a commitment to reduce CO_2 emissions. Recent international negotiations, however, including a 2009 meeting in Copenhagen, Denmark, have yet to reach a consensus on a global strategy to reduce greenhouse gas emissions. Some countries have resisted taking action because a few scientists and policymakers think that the warming trend may be just a random fluctuation in temperature and/or not related to human activities or that cutting CO_2 emissions would sacrifice economic growth. Do you think we need more evidence before taking action? Or is it better to act now to reduce CO_2 emissions? What are the possible costs and benefits of each of these two strategies?
16. The use of biofuels (see chapter introduction) avoids many of the problems associated with gathering, refining, transporting, and burning fossil fuels. Yet biofuels are not without their own set of problems. What challenges do you think would arise from a large-scale conversion to biofuels? How do these challenges compare with those encountered with fossil fuels? Do you think any other types of energy sources have more benefits and fewer costs than the others? Which ones, and why?

Answers to all questions can be found in Appendix 1.

UNIT II

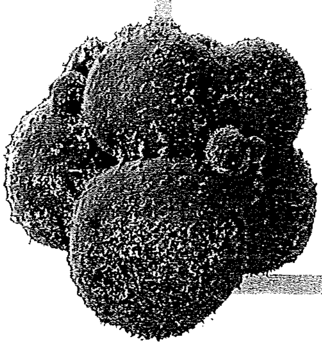
Cellular Reproduction and Genetics



CHAPTER

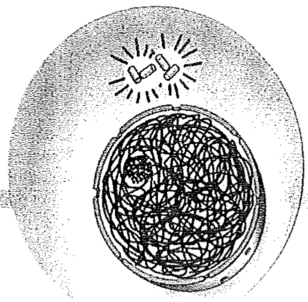
7 The Cellular Basis of Reproduction and Inheritance

BIG IDEAS



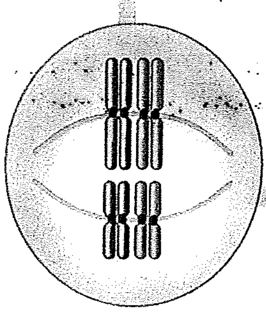
Cell Division and Reproduction
(7.1–7.2)

Cell division underlies many of life's important processes.



The Eukaryotic Cell Cycle and Mitosis
(7.3)

Cells produce genetic duplicates through an ordered, tightly controlled series of steps.



Meiosis and Crossing Over
(7.4–7.6)

The process of meiosis produces genetically varied haploid gametes from diploid cells.

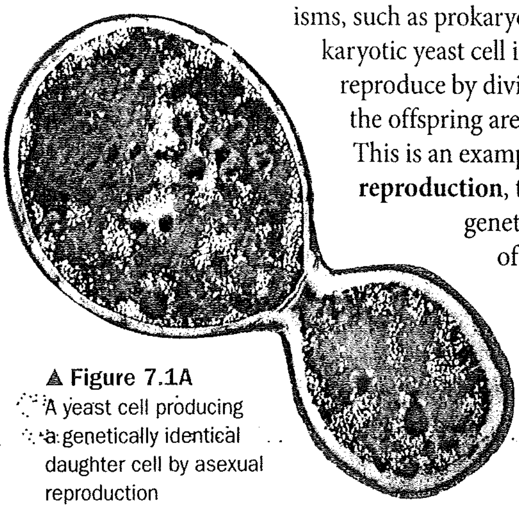
Cell Division and Reproduction

7.1 Cell division plays many important roles in the lives of organisms

The ability of organisms to reproduce their own kind is the one characteristic that best distinguishes living things from nonliving matter (see Module 1.1 to review the characteristics of life). Only amoebas produce more amoebas, only people make more people, and only maple trees produce more maple trees. These simple facts of life have been recognized for thousands of years and are summarized by the age-old saying, "Like begets like."

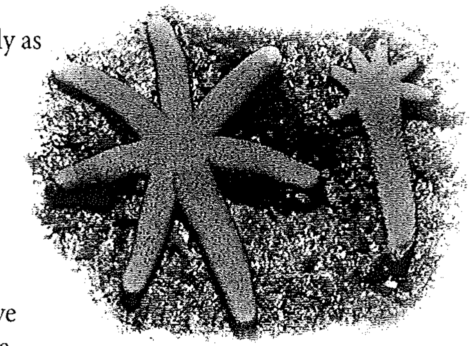
However, the biological concept of reproduction includes more than just the birth of new organisms: Reproduction actually occurs much more often at the cellular level. When a cell undergoes reproduction, or **cell division**, the two "daughter" cells that result are genetically identical to each other and to the original "parent" cell. (Biologists traditionally use the word *daughter* in this context; it does not imply gender.) Before the parent cell splits into two, it duplicates its **chromosomes**, the structures that contain most of the cell's DNA. Then, during the division process, one set of chromosomes is distributed to each daughter cell. As a rule, the daughter cells receive identical sets of chromosomes from the lone, original parent cell. Each offspring cell will thus be genetically identical to the other and to the original parent cell.

Sometimes, cell division results in the reproduction of a whole organism. Many single-celled organisms, such as prokaryotes or the eukaryotic yeast cell in **Figure 7.1A**, reproduce by dividing in half, and the offspring are genetic replicas. This is an example of **asexual reproduction**, the creation of genetically identical offspring by a single parent, without the participation of sperm and egg. Many multicellular organisms can reproduce asexually as well. For example, some sea star species have the ability to grow new individuals from fragmented pieces (**Figure 7.1B**). And if you've ever grown a house plant from a clipping, you've observed asexual reproduction in plants (**Figure 7.1C**). In asexual reproduction, there is one simple principle of inheritance: The lone parent and each of its offspring have identical genes.



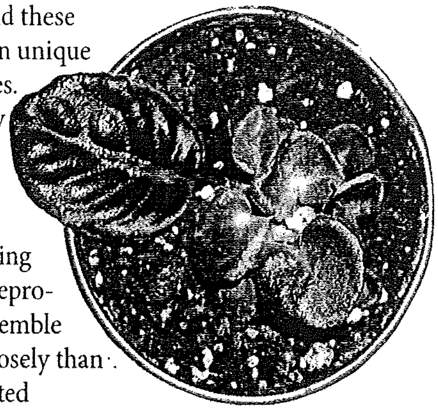
Colorized TEM 5,000×

▲ **Figure 7.1A** A yeast cell producing a genetically identical daughter cell by asexual reproduction



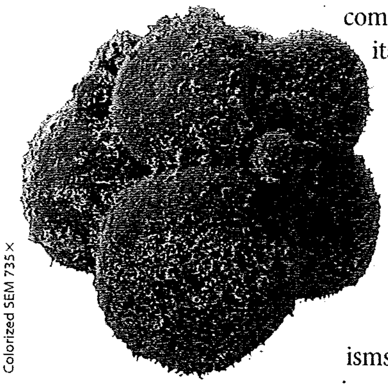
▲ **Figure 7.1B** A sea star reproducing asexually

Sexual reproduction is different; it requires fertilization of an egg by a sperm. The production of gametes—egg and sperm—involves a special type of cell division that occurs only in reproductive organs (such as testes and ovaries in humans). As you'll learn later in the chapter, a gamete has only half as many chromosomes as the parent cell that gave rise to it, and these chromosomes contain unique combinations of genes. Therefore, in sexually reproducing species, like does not precisely beget like (**Figure 7.1D**). Offspring produced by sexual reproduction generally resemble their parents more closely than they resemble unrelated individuals of the same species, but they are not identical to their parents or to each other. Each offspring inherits a unique



▲ **Figure 7.1C** An African violet reproducing asexually from a cutting (the large leaf on the left)

▼ **Figure 7.1D** Sexual reproduction produces offspring with unique combinations of genes

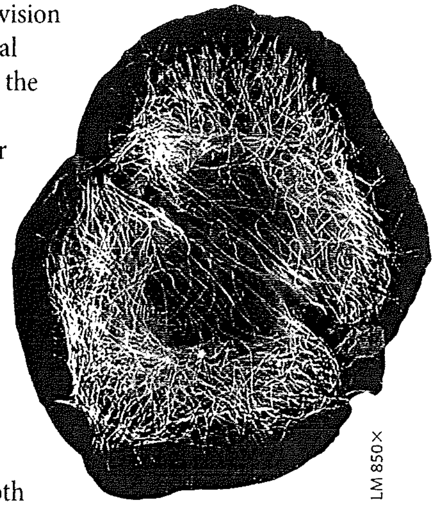


▲ **Figure 7.1E** Dividing cells in an early human embryo

combination of genes from its two parents, and this one-and-only set of genes programs a unique combination of traits. As a result, sexual reproduction can produce great variation among offspring.

In multicellular organisms, cell division plays other important roles, in addition to the production of gametes. Cell division enables sexually reproducing organisms to develop from a single cell—the fertilized egg, or zygote—into an adult organism **(Figure 7.1E)**. All of the trillions of cells in your body arose via repeated cell divisions that began in your mother's body with a single fertilized egg cell. After an organism is fully grown, cell division continues to function in renewal and repair, replacing cells that die from normal wear and tear or accidents. Within your body, millions of cells must divide every second to replace damaged or lost cells **(Figure 7.1F)**.

The type of cell division responsible for asexual reproduction and for the growth and maintenance of multicellular organisms involves a process called mitosis. The production of egg and sperm cells involves a special type of cell division called meiosis. In the remainder of this chapter, you will learn the details of both types of cell division. To start, we'll look briefly at prokaryotic cell division in the next module.



▲ **Figure 7.1F** A human kidney cell dividing

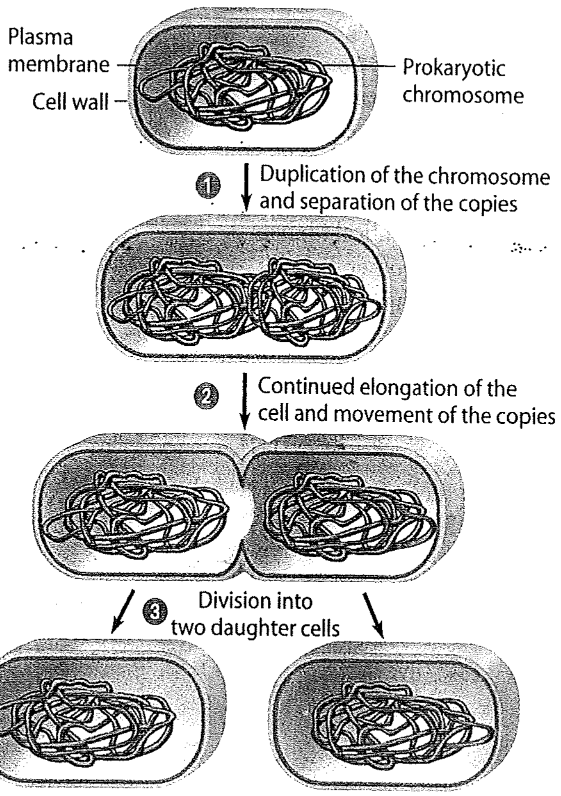
? What function does cell division play in an amoeba? What functions does it play in your body?

Reproduction; development, growth, and repair.

7.2 Prokaryotes reproduce by binary fission

Prokaryotes (bacteria and archaea) reproduce by a type of cell division called **binary fission** ("dividing in half"). In typical prokaryotes, the majority of genes are carried on a single circular DNA molecule that, with associated proteins, constitutes the organism's chromosome. Although prokaryotic chromosomes are much smaller than those of eukaryotes, duplicating them in an orderly fashion and distributing the copies equally to two daughter bacteria is still a formidable task. Consider, for example, that when stretched out, the chromosome of the bacterium *Escherichia coli* (*E. coli*) is about 500 times longer than the cell itself. Accurately replicating this molecule when it is coiled and packed inside the cell is no small achievement.

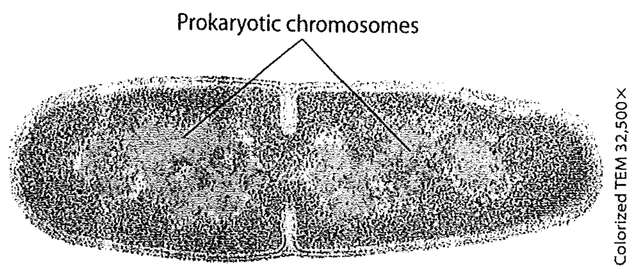
Figure 7.2A illustrates binary fission in a prokaryote. ❶ As the chromosome is duplicating, the copies move toward the opposite ends of the cell. ❷ Meanwhile, the cell elongates. ❸ When chromosome duplication is complete and the cell has reached about twice its initial size, the plasma membrane grows inward and more cell wall is made, dividing the parent cell into two daughter cells. **Figure 7.2B** is an electron micrograph of a dividing bacterium (this cell is at a stage similar to the third illustration in Figure 7.2A).



▲ **Figure 7.2A** Binary fission of a prokaryotic cell

? Why is binary fission classified as asexual reproduction?

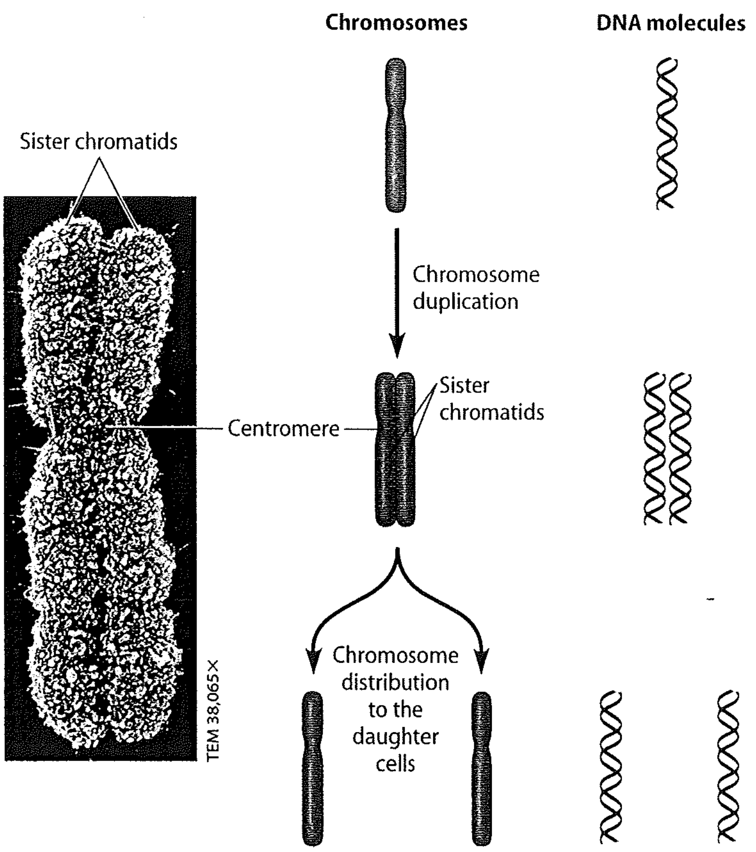
Because the genetically identical offspring inherit their DNA from a single parent.



▲ **Figure 7.2B** An electron micrograph of a dividing bacterium

The Eukaryotic Cell Cycle and Mitosis

7.3 The large, complex chromosomes of eukaryotes duplicate with each cell division



▲ **Figure 7.3B** Chromosome duplication and distribution

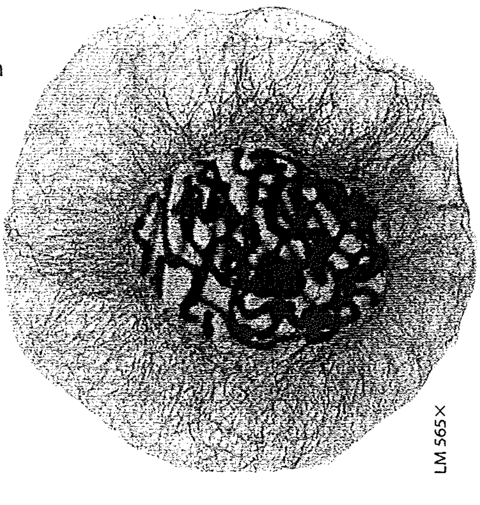
Eukaryotic cells, in general, are more complex and much larger than prokaryotic cells, and they have many more genes. Human cells, for example, carry around 21,000 genes, versus about 3,000 for a typical bacterium. Almost all the genes in the cells of humans, and in all other eukaryotes, are found in the cell nucleus, grouped into multiple chromosomes. (The exceptions include genes on the small DNA molecules of mitochondria and, in plants, chloroplasts.)

Most of the time, chromosomes exist as a diffuse mass of long, thin fibers that, if stretched out, would be far too long to fit in a cell's nucleus. In fact, the total length of DNA in just one of your cells would exceed your total height! DNA in this loose state is called **chromatin,** fibers composed of roughly equal amounts of DNA and protein molecules. Chromatin is too thin to be seen using a light microscope.

As a cell prepares to divide, its chromatin coils up, forming tight, distinct chromosomes that are visible under a light microscope. Why is it necessary for a cell's chromosomes to be compacted in this way? Imagine a situation from your own life: Your belongings are spread out over a considerable area of your home, but as you prepare to move to a new home, you need to gather them all up and pack them into small containers. Similarly, before a cell can undergo division, it must compact all its DNA into manageable packages. **Figure 7.3A** is a micrograph of a plant cell that is about to divide; each thick purple thread is a tightly packed individual chromosome.

Like a prokaryotic chromosome, each eukaryotic chromosome contains one long DNA molecule bearing hundreds or thousands of genes and, attached to the DNA, a number of protein molecules. However, the eukaryotic chromosome has a much more complex structure than the prokaryotic chromosome. The eukaryotic chromosome includes many more protein molecules, which help maintain the chromosome's structure and control the activity of its genes. The number of chromosomes in a eukaryotic cell depends on the species. For example, human body cells generally have 46 chromosomes, while the body cells of a dog have 78.

▶ **Figure 7.3A** A plant cell (from an African blood lily) just before cell division



The chromosomes of a eukaryotic cell are duplicated before they condense and the cell divides. The DNA molecule of each chromosome is replicated (as you'll learn in Chapter 9), and new protein molecules attach as needed. Each chromosome now consists of two copies called **sister chromatids,** which contain identical copies of the DNA molecule **(Figure 7.3B).** The two sister chromatids are joined together especially tightly at a narrow "waist" called the **centromere** (visible near the center of each chromosome shown in the figure).

When the cell divides, the sister chromatids of a duplicated chromosome separate from each other. Once separated from its sister, each chromatid is called a chromosome, and it is identical to the chromosome the cell started with. One of the new chromosomes goes to one daughter cell, and the other goes to the other daughter cell. In this way, each daughter cell receives a complete and identical set of chromosomes. In humans, for example, a typical dividing cell has 46 duplicated chromosomes (or 92 chromatids), and each of the two daughter cells that results from it has 46 single chromosomes.

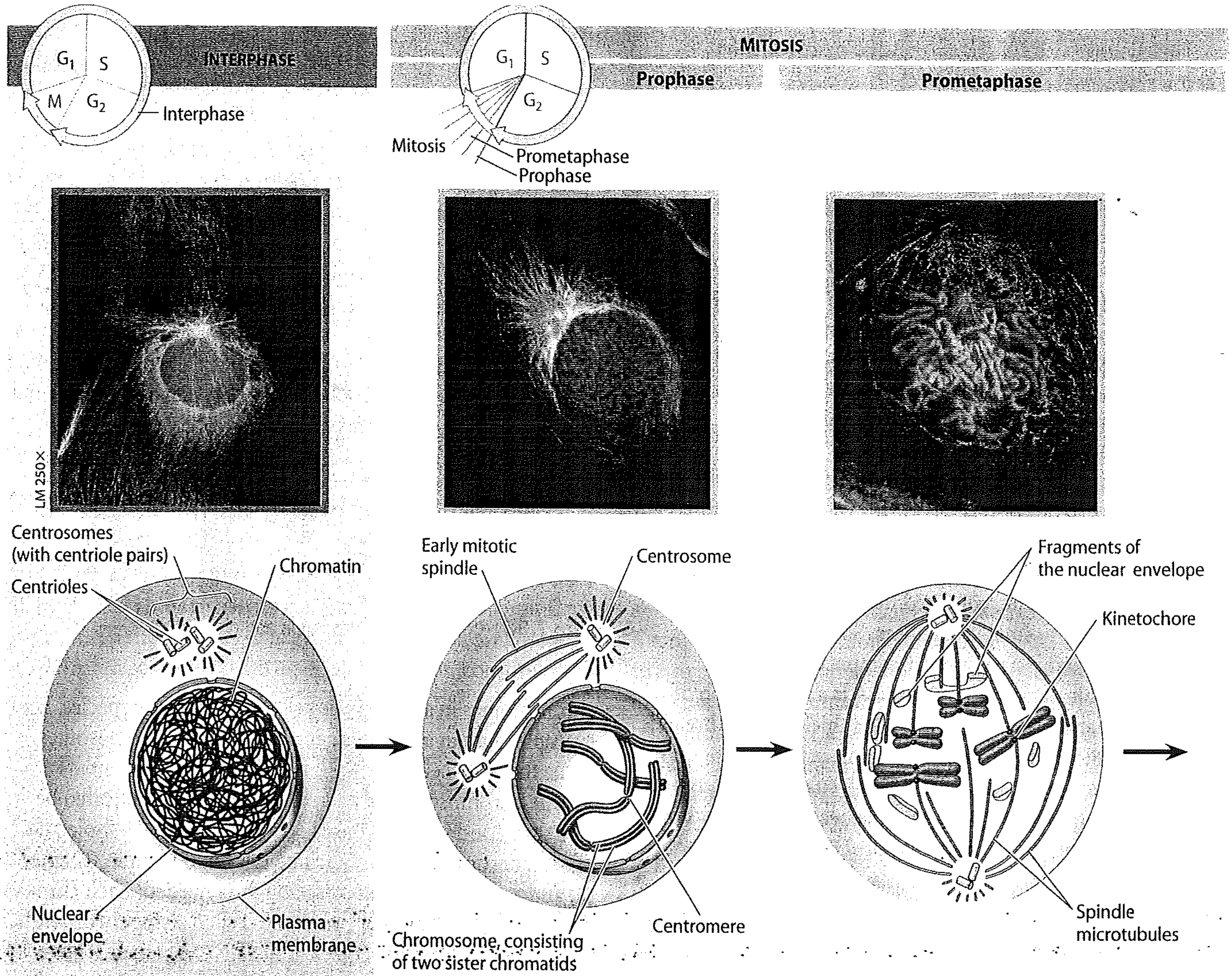
? **When does a chromosome consist of two identical chromatids?**

When the cell is preparing to divide and has duplicated its chromosomes, but before the duplicates actually separate.

Meiosis and Crossing Over

7.4 Cell division is a continuum of dynamic changes

Figure 7.4 illustrates the cell cycle for an animal cell using micrographs, drawings (simplified to include just four chromosomes), and text. The micrographs show cells from a newt, with chromosomes in blue and the mitotic spindle in green. Interphase is included, but the emphasis is on the dramatic changes that occur during cell division, the mitotic phase. Mitosis is a continuum, but biologists distinguish five main stages: **prophase**, **prometaphase**, **metaphase**, **anaphase**, and **telophase**.



Interphase Interphase is the period of cell growth, when the cell synthesizes new molecules and organelles. At the point shown here, during late interphase (G_2), the cell has doubled much of its earlier contents and the cytoplasm contains two centrosomes. Each centrosome has a pair of centrioles, can-shaped structures made of microtubules. Within the nucleus, the chromosomes are duplicated, but they cannot be distinguished individually because they are still in the form of loosely packed chromatin.

Prophase During prophase, changes occur in both the nucleus and the cytoplasm. Within the nucleus, the chromatin fibers become more tightly coiled and folded, forming discrete chromosomes that can be seen with the light microscope. Each duplicated chromosome appears as two identical sister chromatids joined together, with a narrow "waist" at the centromere. In the cytoplasm, the mitotic spindle begins to form as microtubules rapidly grow out from the centrosomes, which begin to move away from each other.

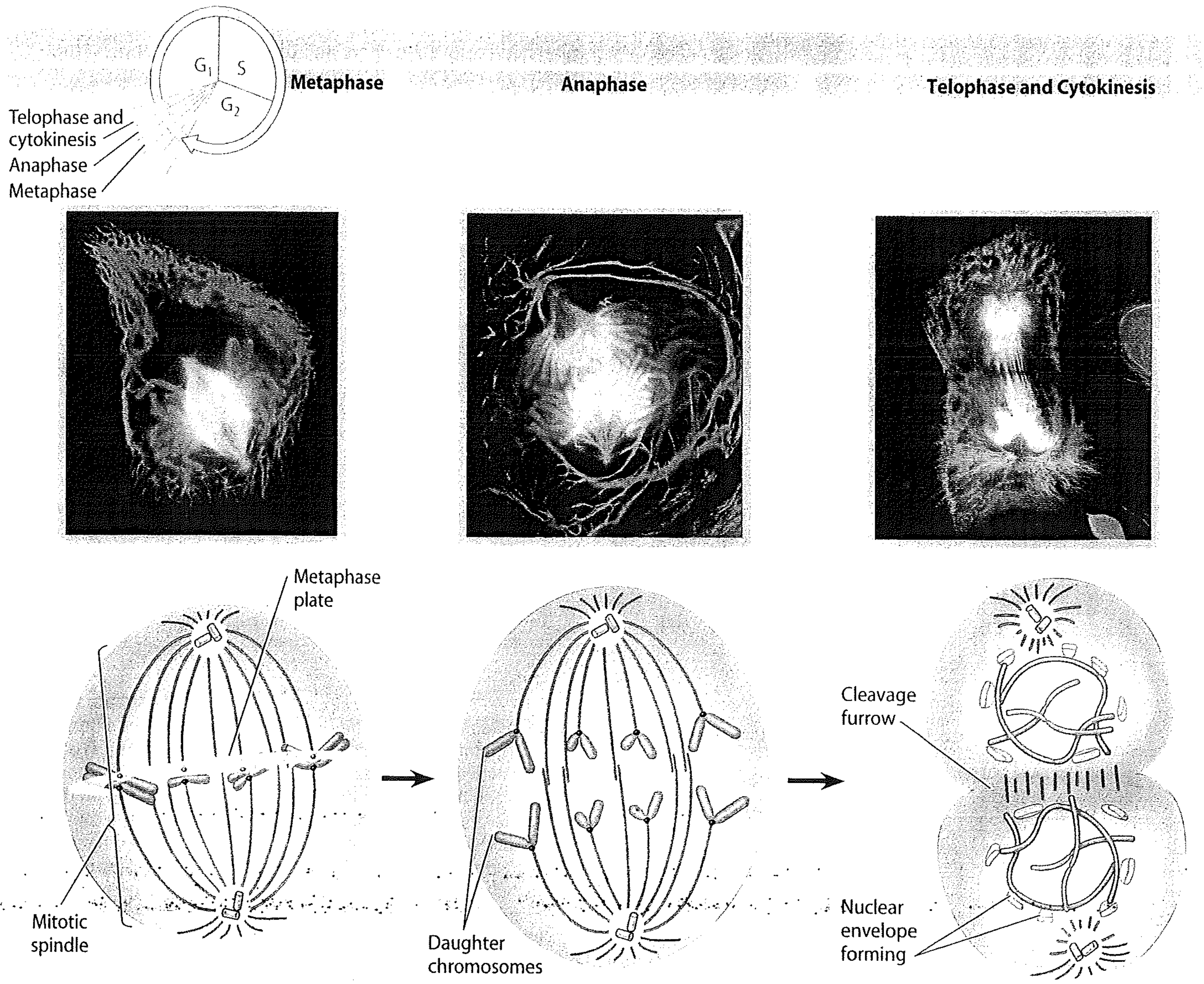
Prometaphase The nuclear envelope breaks into fragments and disappears. Microtubules emerging from the centrosomes at the poles (ends) of the mitotic spindle reach the chromosomes, now highly condensed. At the centromere region, each sister chromatid has a protein structure called a kinetochore (shown as a black dot). Some of the spindle microtubules attach to the kinetochores, throwing the chromosomes into agitated motion. Other spindle microtubules make contact with microtubules coming from the opposite pole. Forces exerted by protein "motors" associated with spindle microtubules move the chromosomes toward the center of the cell.

▲ **Figure 7.4** The stages of cell division by mitosis

The chromosomes are the stars of the mitotic drama. Their movements depend on the **mitotic spindle**, a football-shaped structure of microtubules that guides the separation of the two sets of daughter chromosomes. The spindle microtubules emerge from two **centrosomes**, clouds of cytoplasmic material that in animal cells contain pairs of centrioles (see Chapter 3 for more information on centrioles). Centrosomes are also known as *microtubule-organizing centers*, a term describing their function.

? You view an animal cell through a microscope and observe dense, duplicated chromosomes scattered throughout the cell. Which state of mitosis are you looking at?

Prophase (since the chromosomes are condensed but not yet aligned).



Metaphase At metaphase, the mitotic spindle is fully formed, with its poles at opposite ends of the cell. The chromosomes convene on the metaphase plate, an imaginary plane equidistant between the two poles of the spindle. The centromeres of all the chromosomes are lined up on the metaphase plate. For each chromosome, the kinetochores of the two sister chromatids face opposite poles of the spindle. The microtubules attached to a particular chromatid all come from one pole of the spindle, and those attached to its sister chromatid come from the opposite pole.

Anaphase Anaphase begins when the two centromeres of each chromosome come apart, separating the sister chromatids. Once separate, each sister chromatid is considered a full-fledged (daughter) chromosome. Motor proteins of the kinetochores, powered by ATP, "walk" the daughter chromosomes centromere-first along the microtubules toward opposite poles of the cell. As this happens, the spindle microtubules attached to the kinetochores shorten. However, the spindle microtubules not attached to chromosomes lengthen. The poles are moved farther apart, elongating the cell. Anaphase is over when the chromosomes have reached the two poles of the cell.

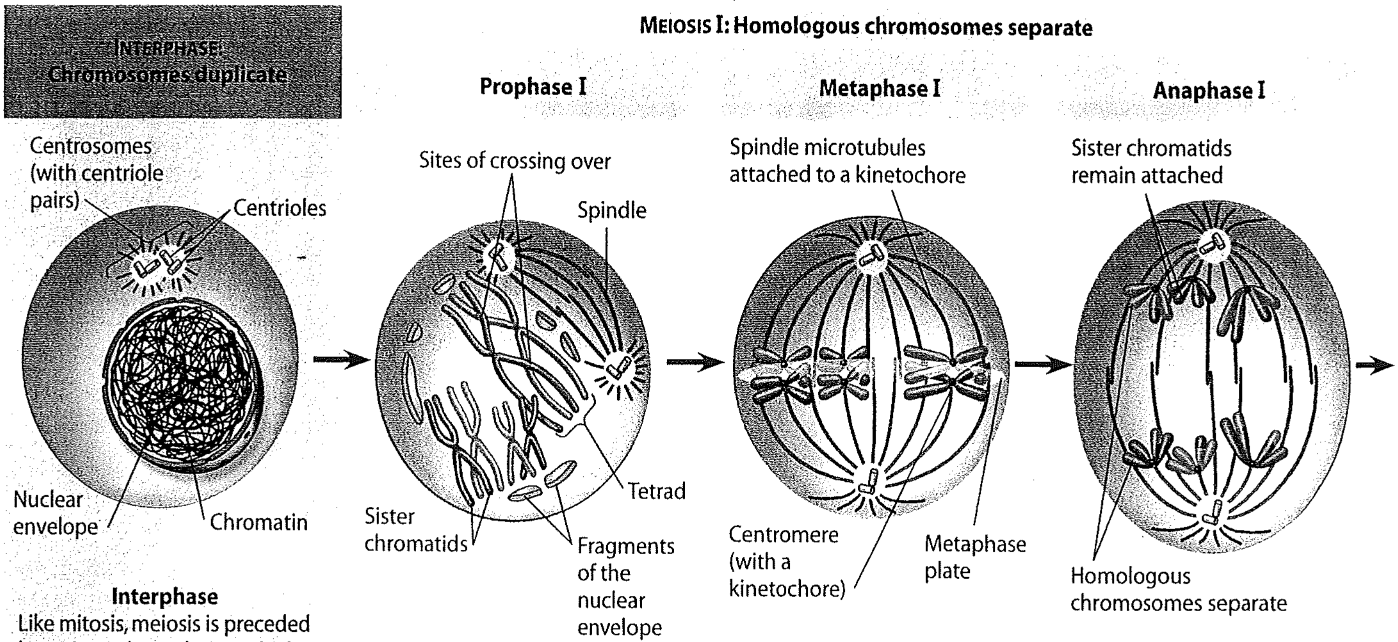
Telophase The cell elongation that started in anaphase continues. Daughter nuclei appear at the two poles of the cell as nuclear envelopes form around the chromosomes. In terms of chromosome and spindle structure, telophase is roughly the reverse of prophase. By the end of telophase, the chromatin fiber of each chromosome uncoils, and the mitotic spindle disappears. Mitosis, the equal division of one nucleus into two genetically identical daughter nuclei, is now finished.

Cytokinesis Cytokinesis, the division of the cytoplasm, usually occurs along with telophase, with two daughter cells completely separating soon after the end of mitosis. In animal cells, a cleavage furrow forms and the cell pinches into two.

7.5 Meiosis reduces the chromosome number from diploid to haploid

Meiosis is a type of cell division that produces haploid gametes in diploid organisms. Two haploid gametes may then combine via fertilization to restore the diploid state in the zygote. Were it not for meiosis, each generation would have twice as much genetic material as the generation before!

Many of the stages of meiosis closely resemble corresponding stages in mitosis. Meiosis, like mitosis, is preceded by the duplication of chromosomes. However, this single duplication is followed by two consecutive cell divisions, called meiosis I and meiosis II. Because one duplication of the chromosomes is followed by two divisions, each of the four daughter cells resulting from meiosis has a haploid set of chromosomes—half as many chromosomes as the parent cell. The drawings in **Figure 7.5** show the two meiotic divisions for an animal cell with a diploid number of 6. The members of a pair of homologous chromosomes in Figure 7.5 (and later figures) are colored red and blue to help distinguish them. (Imagine that the red chromosomes were inherited from the mother and the blue chromosomes from the father.) One of the most important events in meiosis



Interphase
Like mitosis, meiosis is preceded by an interphase, during which the chromosomes duplicate. At the end of interphase, each chromosome consists of two genetically identical sister chromatids attached together. The cell's centrosome has also duplicated by the end of this interphase.

Prophase I
Early in this phase, the chromatin coils up, so that individual chromosomes become visible with the microscope. In a process called **synapsis**, homologous chromosomes, each composed of two sister chromatids, come together as pairs. The resulting structure, consisting of four chromatids, is called a tetrad.

During synapsis, chromatids of homologous chromosomes exchange segments in a process called crossing over. Because the versions of some genes on a chromosome differ from those on its homolog, crossing over rearranges genetic information. The genetic shuffling produced by crossing over can make an important contribution to the genetic variability resulting from sexual reproduction.

As prophase I continues, the chromosomes condense further. The centrosomes move away from each other, and a spindle forms between them. The nuclear envelope breaks into fragments, and the chromosome tetrads, captured by spindle microtubules, are moved toward the center of the cell.

Metaphase I
At metaphase I, the chromosome tetrads are aligned on the metaphase plate, midway between the two poles of the spindle. Each chromosome is condensed and thick, with its sister chromatids still attached at their centromeres. Spindle microtubules are attached to kinetochores at the centromeres. In each tetrad, the homologous chromosomes are held together at sites of crossing over. Notice that, for each tetrad, the spindle microtubules attached to one of the homologous chromosomes come from one pole of the cell, and the microtubules attached to the other homologous chromosome come from the opposite pole. With this arrangement, the homologous chromosomes of each tetrad are poised to move toward opposite poles of the cell.

Anaphase I
Like anaphase of mitosis, anaphase I of meiosis is marked by the migration of chromosomes toward the two poles of the cell. In contrast to mitosis, however, the sister chromatids making up each doubled chromosome remain attached at their centromeres. Only the tetrads (pairs of homologous chromosomes) split up. Thus, in the drawing you see three still-doubled chromosomes (the haploid number) moving toward each spindle pole. If this were anaphase of mitosis, you would see six daughter chromosomes moving toward each pole.

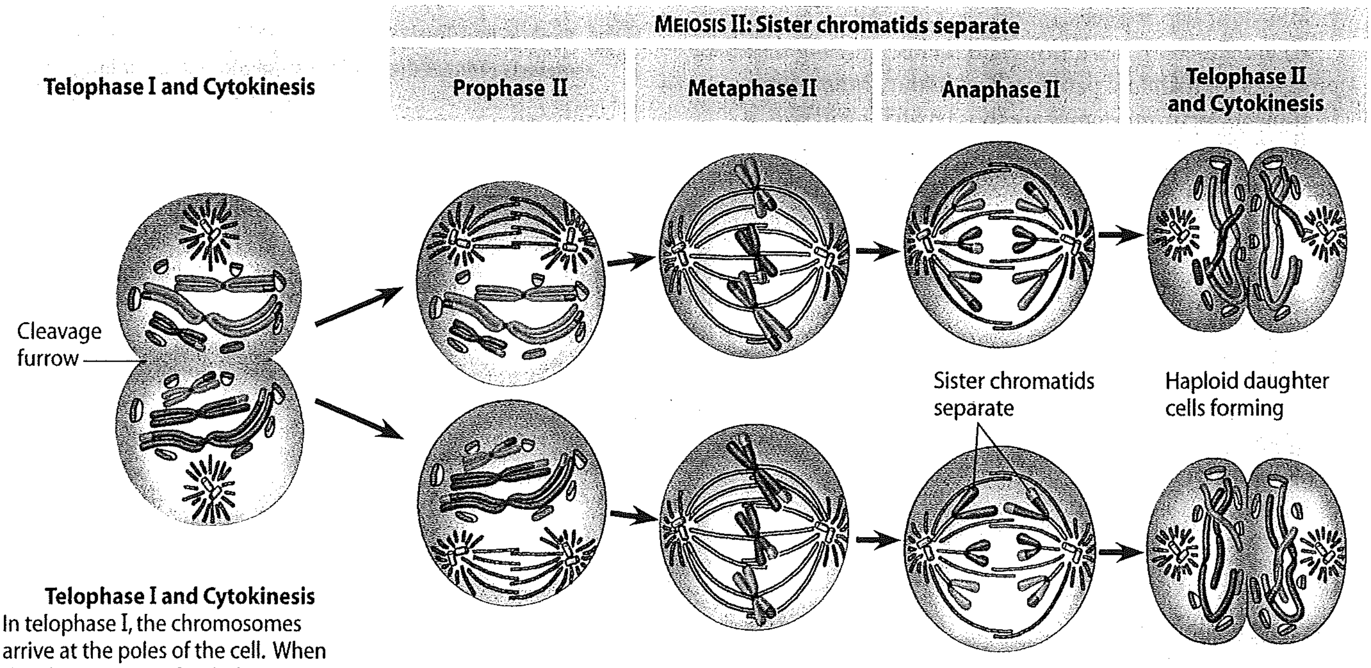
▲ **Figure 7.5** The stages of meiosis

occurs during prophase I. At this stage, four chromatids (two sets of sister chromatids) are aligned and physically touching each other. When in this configuration, nonsister chromatids may trade segments. This exchange of chromosome segments—called crossing over—is a key step in the generation of genetic diversity that occurs during sexual reproduction.

? A cell has the haploid number of chromosomes, but each chromosome has two chromatids. The chromosomes are arranged singly at the center of the spindle. What is the meiotic stage?

Metaphase II (since the chromosomes line up two by two in metaphase I).

Two lily cells undergo meiosis II



Telophase I and Cytokinesis

In telophase I, the chromosomes arrive at the poles of the cell. When the chromosomes finish their journey, each pole of the cell has a haploid chromosome set, although each chromosome is still in duplicate form at this point. In other words, each chromosome still consists of two sister chromatids. Usually, cytokinesis occurs along with telophase I, and two haploid daughter cells are formed.

Following telophase I in some organisms, the chromosomes uncoil and the nuclear envelope re-forms, and there is an interphase before meiosis II begins. In other species, daughter cells produced in the first meiotic division immediately begin preparation for the second meiotic division. In either case, no chromosome duplication occurs between telophase I and the onset of meiosis II.

Meiosis II

Meiosis II is essentially the same as mitosis. The important difference is that meiosis II starts with a haploid cell.

During prophase II, a spindle forms and moves the chromosomes toward the middle of the cell. During metaphase II, the chromosomes are aligned on the metaphase plate as they are in mitosis, with the kinetochores of the sister chromatids of each chromosome pointing toward opposite poles. In anaphase II, the centromeres of sister chromatids finally separate, and the sister chromatids of each pair, now individual daughter chromosomes, move toward opposite poles of the cell. In telophase II, nuclei form at the cell poles, and cytokinesis occurs at the same time. There are now four daughter cells, each with the haploid number of (single) chromosomes.

7.6 Mitosis and meiosis have important similarities and differences

You have now learned the two ways that cells of eukaryotic organisms divide. Mitosis, which provides for growth, tissue repair, and asexual reproduction, produces daughter cells that are genetically identical to the parent cell. Meiosis, needed for sexual reproduction, yields genetically unique haploid daughter cells—cells with only one member of each homologous chromosome pair.

For both mitosis and meiosis, the chromosomes duplicate only once, during the S phase of the preceding interphase. Mitosis involves one division of the nucleus, and it is usually accompanied by cytokinesis, producing two identical diploid cells. Meiosis entails two nuclear and cytoplasmic divisions, yielding four haploid cells.

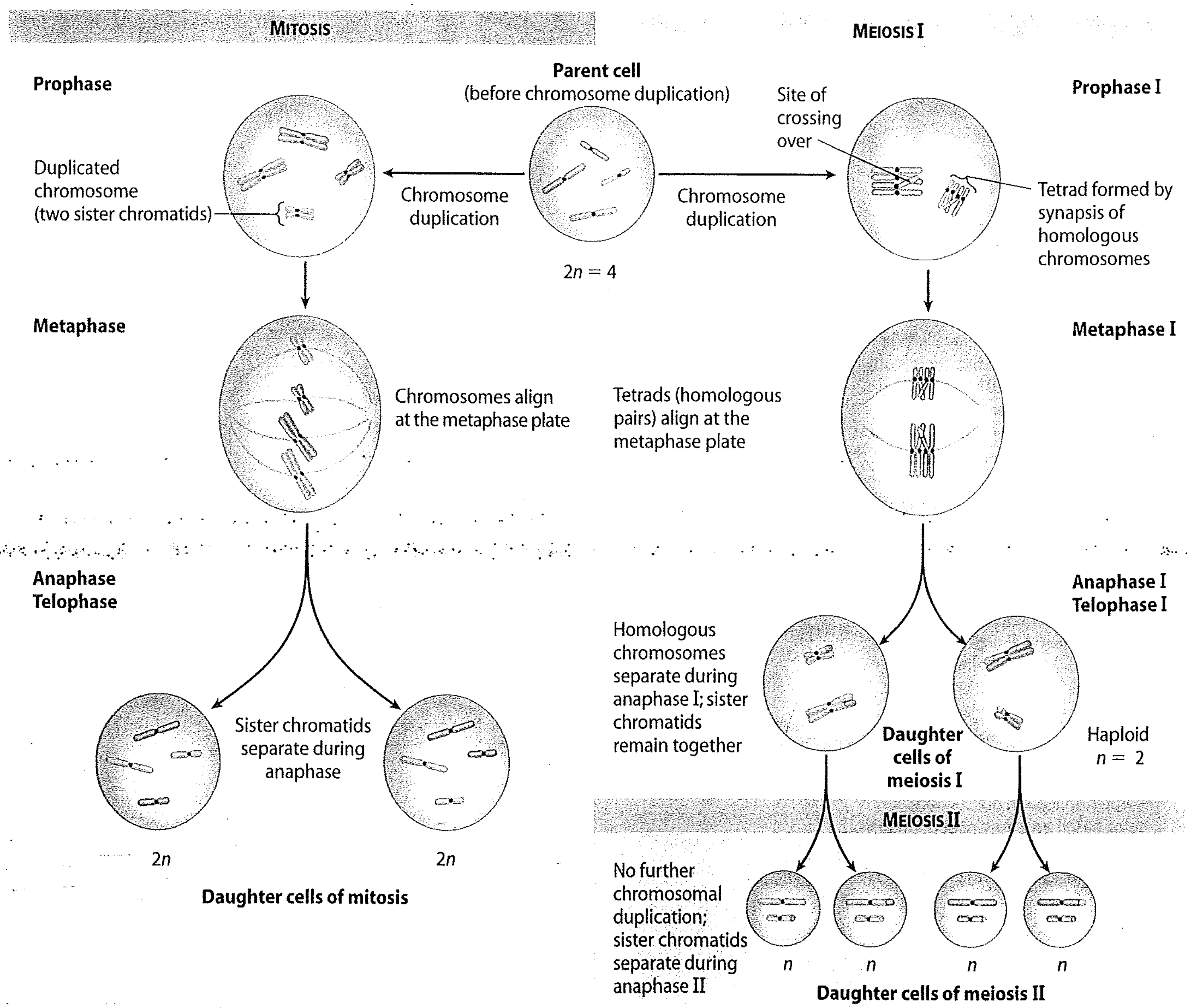
Figure 7.6 compares mitosis and meiosis, tracing these two processes for a diploid parent cell with four chromosomes. Homologous chromosomes are those matching in size.

Notice that all the events unique to meiosis occur during meiosis I. In prophase I, duplicated homologous chromosomes pair to form **tetrads**, sets of four chromatids, with each pair of sister chromatids joined at their centromeres. In metaphase I, tetrads (not individual chromosomes) are aligned at the metaphase plate. During anaphase I, pairs of homologous chromosomes separate, but the sister chromatids of each chromosome stay together. At the end of meiosis I, there are two haploid cells, but each chromosome still has two sister chromatids.

Meiosis II is virtually identical to mitosis in that it separates sister chromatids. But unlike mitosis, each daughter cell produced by meiosis II has only a *haploid* set of chromosomes.

? Explain how mitosis conserves chromosome number while meiosis reduces the number from diploid to haploid.

In mitosis, the duplication of chromosomes is followed by one division of the cell. In meiosis, homologous chromosomes separate in the first of two cell divisions; after the second division, each new cell ends up with just a single haploid set.



▲ **Figure 7.6** Comparison of mitosis and meiosis

CHAPTER 7 REVIEW

Reviewing the Concepts

Cell Division and Reproduction (7.1–7.2)

7.1 Cell division plays many important roles in the lives of organisms. Cell division is at the heart of the reproduction of cells and organisms because cells come only from preexisting cells. Some organisms reproduce through asexual reproduction, and their offspring are all genetic copies of the parent and of each other. Others reproduce through sexual reproduction, creating a variety of offspring, each with a unique combination of traits.

7.2 Prokaryotes reproduce by binary fission. Prokaryotic cells reproduce asexually by cell division. As the cell replicates its single chromosome, the copies move apart; the growing membrane then divides the cell.

The Eukaryotic Cell Cycle and Mitosis (7.3)

7.3 The large, complex chromosomes of eukaryotes duplicate with each cell division. A eukaryotic cell has many more genes than a prokaryotic cell, and they are grouped into multiple chromosomes in the nucleus. Each chromosome contains one very long DNA molecule associated with proteins. Individual chromosomes are visible only when the cell is in the process of dividing; otherwise, they are in the form of thin, loosely packed chromatin fibers. Before a cell starts dividing, the chromosomes duplicate, producing sister chromatids (containing identical DNA) that are joined together. Cell division involves the separation of sister chromatids and results in two daughter cells, each containing a complete and identical set of chromosomes.

Meiosis and Crossing Over (7.4–7.6)

7.4 Cell division is a continuum of dynamic changes. Mitosis distributes duplicated chromosomes into two daughter nuclei. After the chromosomes are coiled up, a mitotic spindle made of microtubules moves them to the middle of the cell. The sister chromatids then separate and move to opposite poles of the cell, where two new nuclei form. Cytokinesis, in which the cell divides in two, overlaps the end of mitosis.

7.5 Meiosis reduces the chromosome number from diploid to haploid. Meiosis, like mitosis, is preceded by chromosome duplication, but in meiosis, the cell divides twice to form four daughter cells. The first division, meiosis I, starts with synapsis, the pairing of homologous chromosomes. In crossing over, homologous chromosomes exchange corresponding segments. Meiosis I separates the members of each homologous pair and produces two daughter cells, each with one set of chromosomes. Meiosis II is essentially the same as mitosis: In each of the cells, the sister chromatids of each chromosome separate. The result is a total of four haploid cells.

7.6 Mitosis and meiosis have important similarities and differences. Both mitosis and meiosis begin with diploid parent cells that have chromosomes duplicated during the previous interphase. But mitosis produces two genetically identical diploid somatic daughter cells, while meiosis produces four genetically unique haploid gametes.

Connecting the Concepts

1. Complete the following table to compare mitosis and meiosis.

	Mitosis	Meiosis
Number of chromosomal duplications		
Number of cell divisions		
Number of daughter cells produced		
Number of chromosomes in the daughter cells		
How the chromosomes line up during metaphase		
Genetic relationship of the daughter cells to the parent cell		
Functions performed in the human body		

Testing Your Knowledge

Multiple Choice

2. If an intestinal cell in a grasshopper contains 24 chromosomes, then a grasshopper sperm cell contains ______ chromosomes.
   a. 3
   b. 6
   c. 12
   d. 24
   e. 48

3. Which of the following phases of mitosis is essentially the opposite of prophase in terms of nuclear changes?
   a. telophase
   b. metaphase
   c. S phase
   d. interphase
   e. anaphase

4. A biochemist measured the amount of DNA in cells growing in the laboratory and found that the quantity of DNA in a cell doubled
   a. between prophase and anaphase of mitosis.
   b. between the G_1 and G_2 phases of the cell cycle.
   c. during the M phase of the cell cycle.
   d. between prophase I and prophase II of meiosis.
   e. between anaphase and telophase of mitosis.

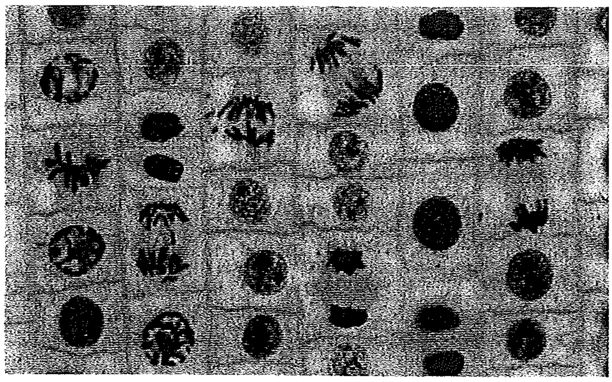
5. Which of the following is *not* a function of mitosis in humans?
   a. repair of wounds
   b. growth
   c. production of gametes from diploid cells
   d. replacement of lost or damaged cells
   e. multiplication of somatic cells

6. A micrograph of a dividing cell from a mouse showed 19 chromosomes, each consisting of two sister chromatids. During which of the following stages of cell division could such a picture have been taken? (*Explain your answer.*)
   a. prophase of mitosis
   b. telophase II of meiosis
   c. prophase I of meiosis
   d. anaphase of mitosis
   e. prophase II of meiosis

7. Cytochalasin B is a chemical that disrupts microfilament formation. This chemical would interfere with
   a. DNA replication.
   b. formation of the mitotic spindle.
   c. cleavage.
   d. formation of the cell plate.
   e. crossing over.
8. It is difficult to observe individual chromosomes during interphase because
   a. the DNA has not been replicated yet.
   b. they are in the form of long, thin strands.
   c. they leave the nucleus and are dispersed to other parts of the cell.
   d. homologous chromosomes do not pair up until division starts.
   e. the spindle must move them to the metaphase plate before they become visible.
9. A fruit fly somatic cell contains 8 chromosomes. This means that ______ different combinations of chromosomes are possible in its gametes.
   a. 4
   b. 8
   c. 16
   d. 32
   e. 64
10. If a fragment of a chromosome breaks off and then reattaches to the original chromosome but in the reverse direction, the resulting chromosomal abnormality is called
   a. a deletion.
   b. an inversion.
   c. a translocation.
   d. a nondisjunction.
   e. a reciprocal translocation.

Describing, Comparing, and Explaining

11. An organism called a plasmodial slime mold is one large cytoplasmic mass with many nuclei. Explain how such a "megacell" could form.
12. In the light micrograph opposite of dividing cells near the tip of an onion root, identify a cell in interphase, prophase, metaphase, anaphase, and telophase. Describe the major events occurring at each stage.



13. Compare cytokinesis in plant and animal cells. In what ways are the two processes similar? In what ways are they different?

Applying the Concepts

14. Bacteria are able to divide on a much faster schedule than eukaryotic cells. Some bacteria can divide every 20 minutes, while the minimum time required by eukaryotic cells in a rapidly developing embryo is about once per hour, and most cells divide much less often than that. State several testable hypotheses explaining why bacteria can divide at a faster rate than eukaryotic cells.
15. Red blood cells, which carry oxygen to body tissues, live for only about 120 days. Replacement cells are produced by cell division in bone marrow. How many cell divisions must occur each second in your bone marrow just to replace red blood cells? Here is some information to use in calculating your answer: There are about 5 million red blood cells per cubic millimeter (mm^3) of blood. An average adult has about 5 L (5,000 cm^3) of blood. (*Hint*: What is the total number of red blood cells in the body? What fraction of them must be replaced each day if all are replaced in 120 days?)

Answers to all questions can be found in Appendix 1.

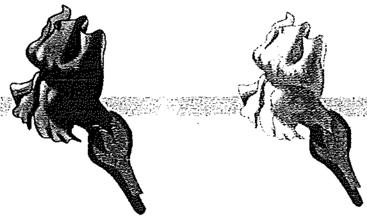
CHAPTER

8 Patterns of Inheritance

BIG IDEAS

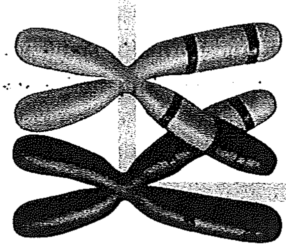
Mendel's Laws
(8.1–8.3)

A few simple and long-established rules explain many aspects of heredity.



Variations on Mendel's Laws
(8.4)

Some inheritance patterns are more complex than the ones described by Mendel.



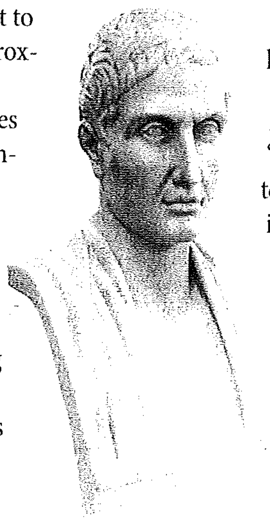
The Chromosomal Basis of Inheritance
(8.5)

Hereditary rules can be understood by following the behavior of chromosomes.

Mendel's Laws

8.1 The science of genetics has ancient roots

Attempts to explain inheritance date back at least to ancient Greece. The physician Hippocrates (approximately 460–370 BCE) suggested an explanation called pangenesis. According to this idea, particles called pangenes travel from each part of an organism's body to the eggs or sperm and then are passed to the next generation; moreover, changes that occur in the body during an organism's life are passed on in this way. The Greek philosopher Aristotle (384–322 BCE; **Figure 8.1**) rejected this idea as simplistic, saying that what is inherited is the potential to produce body features rather than particles of the features themselves.



▲ **Figure 8.1** Aristotle

Actually, pangenesis proves incorrect in several respects. The reproductive cells are not composed of particles from somatic (body) cells, and changes in somatic cells do not influence eggs and sperm. For instance, no matter how much you enlarge your biceps by lifting weights, muscle cells in your arms do not transmit genetic information to your gametes, and your offspring will not be changed by your weight-lifting efforts. This may seem like common sense today, but the pangenesis hypothesis and the idea that traits acquired during an individual's lifetime are passed on to offspring prevailed well into the 19th century.

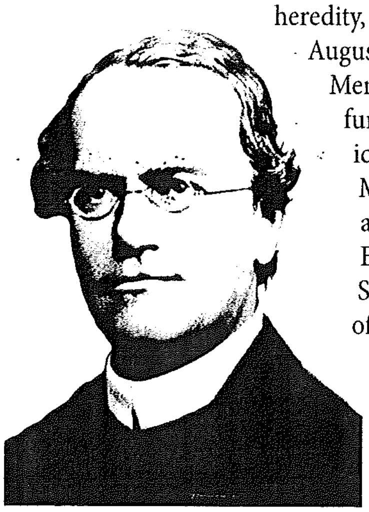
By observing inheritance patterns in ornamental plants, biologists of the early 19th century established that offspring inherit traits from both parents. The favored explanation of inheritance then became the "blending" hypothesis, the idea that the hereditary materials contributed by the male and female parents mix in forming the offspring similar to the way that blue and yellow paints blend to make green. For example, according to this hypothesis, after the genetic information for the colors of black and chocolate brown Labrador retrievers is blended, the colors should be as inseparable as paint pigments. But this is not what happens: Instead, the offspring of a purebred black Lab and a purebred brown Lab will all be black, but some of the dogs in the next generation will be brown. The blending hypothesis was finally rejected because it does not explain how traits that disappear in one generation can reappear in later ones.

? Horse breeders sometimes speak of "mixing the bloodlines" of two pedigrees. In what way is this phrase inaccurate?

It implies the blending hypothesis—that offspring are a blend of two parents, as in a fluid mixture.

8.2 Experimental genetics began in an abbey garden

Heredity is the transmission of traits from one generation to the next. The field of **genetics**, the scientific study of heredity, began in the 1860s, when an Augustinian monk named Gregor Mendel (**Figure 8.2A**) deduced the fundamental principles of genetics by breeding garden peas. Mendel lived and worked in an abbey in Brunn, Austria (now Brno, in the Czech Republic). Strongly influenced by his study of physics, mathematics, and chemistry at the University of Vienna, his research was both experimentally and mathematically rigorous, and these qualities were largely responsible for his success.

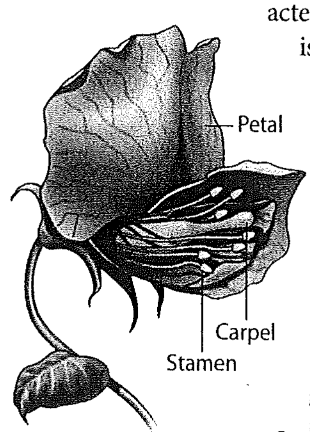


▲ **Figure 8.2A** Gregor Mendel

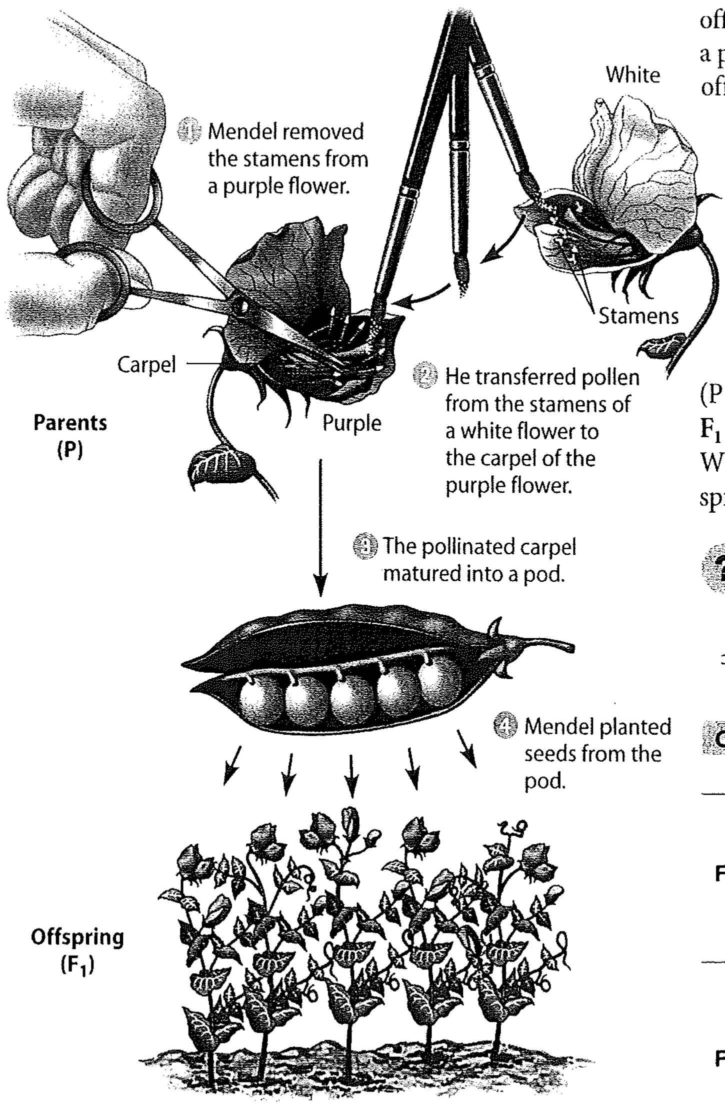
In a paper published in 1866, Mendel correctly argued that parents pass on to their offspring discrete "heritable factors." In his paper, Mendel stressed that the heritable factors, today called genes, retain their individuality generation after generation. That is, genes are like playing cards; a deck may be shuffled, but the cards always retain their original identities, and no card is ever blended with another. Similarly, genes may be rearranged but each gene permanently retains its identity.

Mendel probably chose to study garden peas because they had short generation times, produced large numbers of offspring from each mating, and came in many readily distinguishable varieties. For example, one variety has purple flowers, and another variety has white flowers. A heritable feature that varies among individuals, such as flower color, is called a **character**. Each variant for a character, such as purple or white flowers, is called a **trait**.

Perhaps the most important advantage of pea plants as an experimental model was that Mendel could strictly control matings. As **Figure 8.2B** shows, the petals of the pea flower



◀ **Figure 8.2B** The anatomy of a garden pea flower (with one petal removed to improve visibility)



▲ **Figure 8.2C** Mendel's technique for cross-fertilization of pea plants

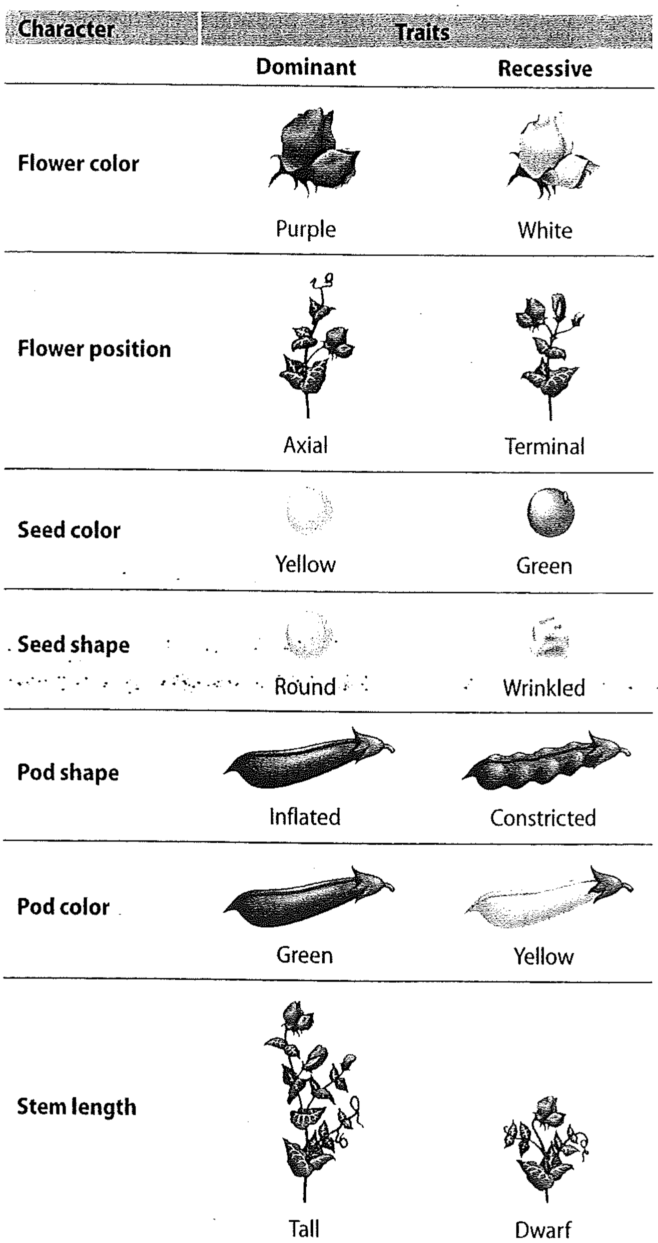
almost completely enclose the reproductive organs: the stamens and carpel. Consequently, pea plants usually are able to **self-fertilize** in nature. That is, sperm-carrying pollen grains released from the stamens land on the egg-containing carpel of the same flower. Mendel could ensure self-fertilization by covering a flower with a small bag so that no pollen from another plant could reach the carpel. When he wanted **cross-fertilization** (fertilization of one plant by pollen from a different plant), he used the method shown in **Figure 8.2C**. 1 He prevented self-fertilization by cutting off the immature stamens of a plant before they produced pollen. 2 To cross-fertilize the stamenless flower, he dusted its carpel with pollen from another plant. After pollination, 3 the carpel developed into a pod, containing seeds (peas) that 4 he planted. The seeds grew into offspring plants. Through these methods, Mendel could always be sure of the parentage of new plants.

Mendel's success was due not only to his experimental approach and choice of organism but also to his selection of characteristics to study. He chose to observe seven characters, each of which occurred as two distinct traits (**Figure 8.2D**). Mendel worked with his plants until he was sure he had **true-breeding** varieties—that is, varieties for which self-fertilization produced offspring all identical to the parent. For instance, he identified a purple-flowered variety that, when self-fertilized, produced offspring plants that all had purple flowers.

Now Mendel was ready to ask what would happen when he crossed his different true-breeding varieties with each other. For example, what offspring would result if plants with purple flowers and plants with white flowers were cross-fertilized? The offspring of two different varieties are called **hybrids**, and the cross-fertilization itself is referred to as a hybridization, or simply a genetic **cross**. The true-breeding parental plants are called the **P generation** (P for parental), and their hybrid offspring are called the **F_1 generation** (F for filial, from the Latin word for "son"). When F_1 plants self-fertilize or fertilize each other, their offspring are the **F_2 generation**. We turn to Mendel's results next.

? Why was the development of true-breeding varieties critical to the success of Mendel's experiments?

True-breeding varieties allowed Mendel to predict the outcome of specific crosses and thus to run controlled experiments.



Character	Traits: Dominant	Traits: Recessive
Flower color	Purple	White
Flower position	Axial	Terminal
Seed color	Yellow	Green
Seed shape	Round	Wrinkled
Pod shape	Inflated	Constricted
Pod color	Green	Yellow
Stem length	Tall	Dwarf

▲ **Figure 8.2D** The seven pea characters studied by Mendel

8.3 Mendel's law of segregation describes the inheritance of a single character

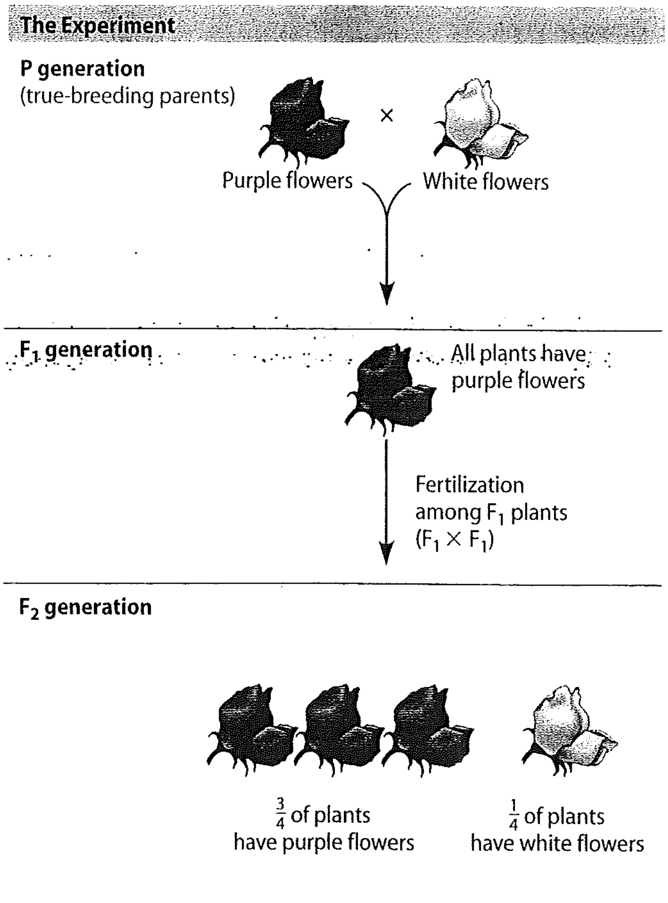
Mendel performed many experiments in which he tracked the inheritance of characters that occur in two forms, such as flower color. The results led him to formulate several hypotheses about inheritance. Let's look at some of his experiments and follow the reasoning that led to his hypotheses.

Figure 8.3A starts with a cross between a true-breeding pea plant with purple flowers and a true-breeding pea plant with white flowers. This is called a **monohybrid cross** because the parent plants differ in only one character—flower color. Mendel observed that F_1 plants all had purple flowers; they were not light purple, as predicted by the blending hypothesis. Was the white-flowered plant's genetic contribution to the hybrids lost? By mating the F_1 plants with each other, Mendel found the answer to be no. Out of 929 F_2 plants, 705 (about $\frac{3}{4}$) had purple flowers and 224 (about $\frac{1}{4}$) had white flowers, a ratio of about three plants with purple flowers to every one with white flowers (abbreviated as 3:1). Mendel reasoned that the heritable factor for white flowers did not disappear in the F_1 plants, but was masked when the purple-flower factor was present. He also deduced that the F_1 plants must have carried two factors for the flower-color character, one for purple and one for white.

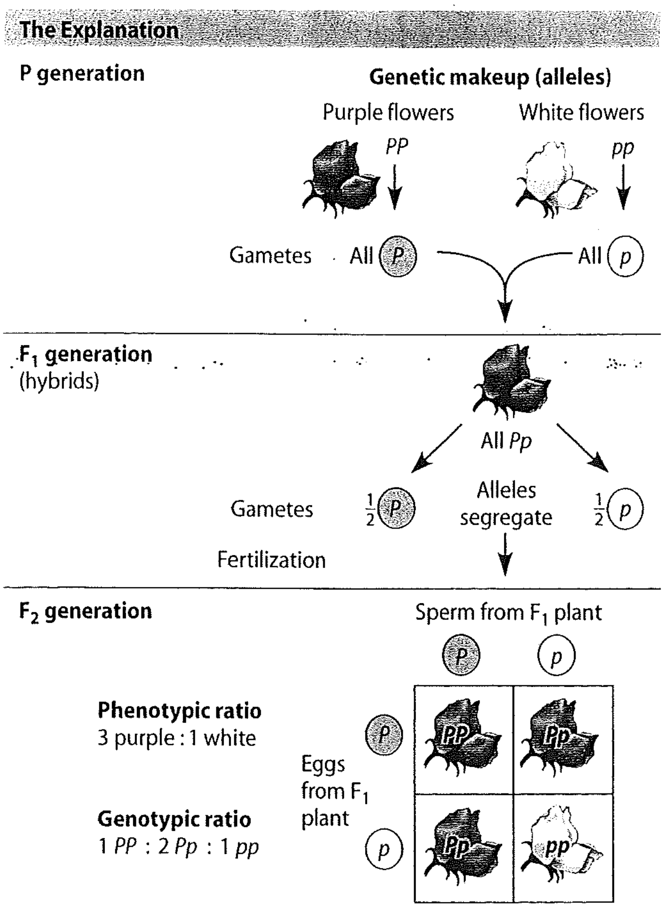
Mendel observed these same patterns of inheritance for six other pea plant characters (see Figure 8.2D). From his results, he developed four hypotheses, described here using modern terminology, such as "gene" instead of "heritable factor."

1. *There are alternative versions of genes that account for variations in inherited characters.* For example, the gene for flower color in pea plants exists in two versions: one for purple and the other for white. The alternative versions of a gene are called **alleles.**
2. *For each character, an organism inherits two alleles, one from each parent.* These alleles may be the same or different. An organism that has two identical alleles for a gene is said to be **homozygous** for that gene (and is a "homozygote" for that trait). An organism that has two different alleles for a gene is said to be **heterozygous** for that gene (and is a "heterozygote").
3. *If the two alleles of an inherited pair differ, then one determines the organism's appearance and is called the* **dominant** *allele; the other has no noticeable effect on the organism's appearance and is called the* **recessive** *allele.* We use uppercase letters to represent dominant alleles and lowercase letters to represent recessive alleles.
4. *A sperm or egg carries only one allele for each inherited character because allele pairs separate (segregate) from each other during the production of gametes.* This statement is called the **law of segregation.** When sperm and egg unite at fertilization, each contributes its allele, restoring the paired condition in the offspring.

Figure 8.3B explains the results in Figure 8.3A. In this example, the letter *P* represents the dominant allele (for purple



▲ **Figure 8.3A** Crosses tracking one character (flower color)



▲ **Figure 8.3B** An explanation of the crosses in Figure 9.3A

flowers), and p stands for the recessive allele (for white flowers). Both parental plants (at the top of the figure) were true-breeding, and Mendel's first two hypotheses propose that one parental variety had two alleles for purple flowers (PP) and the other had two alleles for white flowers (pp).

Consistent with hypothesis 4, the gametes of Mendel's parental plants each carried one allele; thus, the parental gametes in Figure 8.3B are either P or p. As a result of fertilization, the F_1 hybrids each inherited one allele for purple flowers and one for white. Hypothesis 3 explains why all of the F_1 hybrids (Pp) had purple flowers: The dominant P allele has its full effect in the heterozygote, while the recessive p allele has no effect.

Mendel's hypotheses also explain the 3:1 ratio in the F_2 generation. Because the F_1 hybrids are Pp, they make gametes P and p in equal numbers. The bottom diagram in Figure 8.3B, called a **Punnett square**, shows the four possible combinations of alleles that could occur when these gametes combine.

The Punnett square shows the proportions of F_2 plants predicted by Mendel's hypotheses. If a sperm carrying allele P fertilizes an egg carrying allele P, the offspring (PP) will produce purple flowers. Mendel's hypotheses predict that this combination will occur in $\frac{1}{4}$ of the offspring. As shown in the Punnett square, the hypotheses also predict that $\frac{1}{2}$ (or two of four) of the offspring will inherit one P allele and one p allele. These offspring (Pp) will all have purple flowers because P is dominant. The remaining $\frac{1}{4}$ of F_2 plants will inherit two p alleles and will have white flowers.

Because an organism's appearance does not always reveal its genetic composition, geneticists distinguish between an organism's physical traits, called its **phenotype** (such as purple or white flowers), and its genetic makeup, its **genotype** (in this example, PP, Pp, or pp). So now we see that Figure 8.3A shows just phenotypes while Figure 8.3B shows both phenotypes and genotypes in our sample crosses. For the F_2 plants, the ratio of plants with purple flowers to those with white flowers (3:1) is called the phenotypic ratio. The genotypic ratio, as shown by the Punnett square, is 1 PP:2 Pp:1 pp.

Mendel found that each of the seven characteristics he studied exhibited the same inheritance pattern: One parental trait disappeared in the F_1 generation, only to reappear in $\frac{1}{4}$ of the F_2 offspring. The mechanism underlying this inheritance pattern is stated by Mendel's law of segregation: Pairs of alleles segregate (separate) during gamete formation. The fusion of gametes at fertilization creates allele pairs once again. Research since Mendel's time has established that due to the separation of homologous chromosomes during meiosis I (see Modules 7.5–7.6), the law of segregation applies to all sexually reproducing organisms, including humans.

? How can two plants with different genotypes for a particular inherited character be identical in phenotype?

One could be homozygous for the dominant allele and the other heterozygous.

Variations on Mendel's Laws

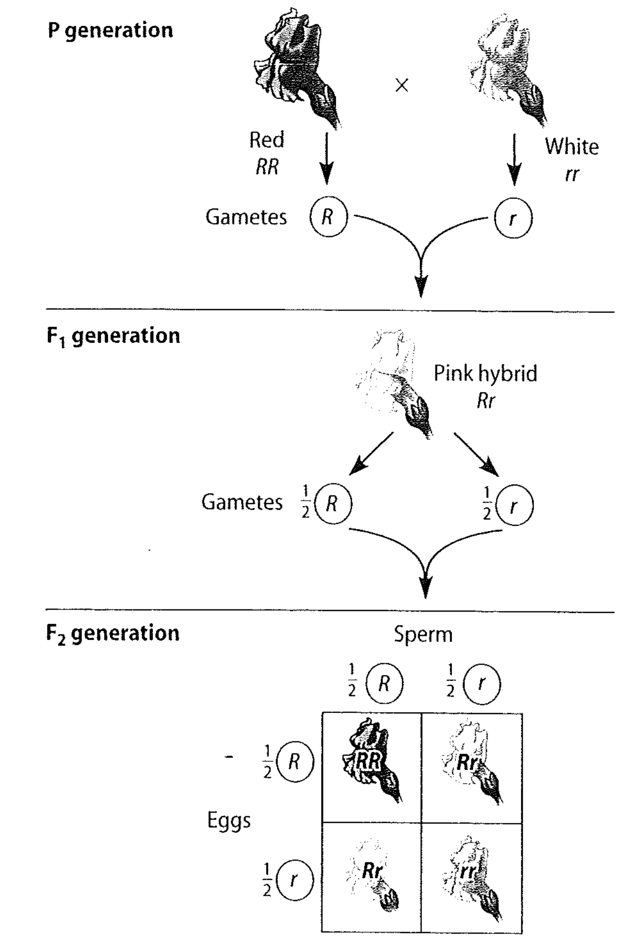
8.4 Incomplete dominance results in intermediate phenotypes

Mendel's laws explain inheritance in terms of discrete factors—genes—that are passed along from generation to generation according to simple rules of probability. Mendel's laws are valid for all sexually reproducing organisms, including garden peas, Labradors, and human beings. But just as the basic rules of musical harmony cannot account for all the rich sounds of a symphony, Mendel's laws stop short of explaining some patterns of genetic inheritance. In fact, for most sexually reproducing organisms, cases where Mendel's laws can strictly account for the patterns of inheritance are relatively rare. More often, the inheritance patterns are more complex, as we will see in this module.

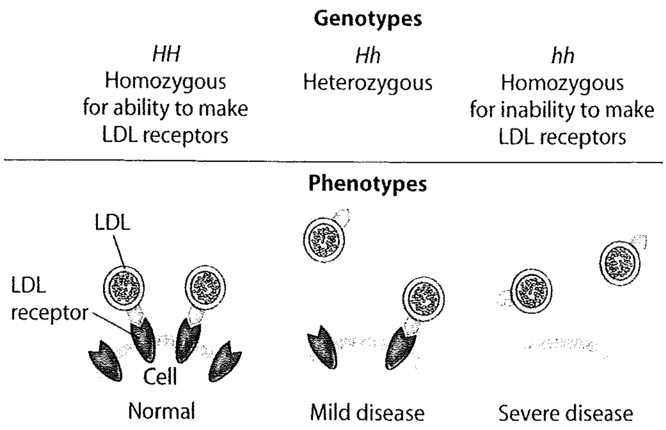
The F_1 offspring of Mendel's pea crosses always looked like one of the two parental varieties. In this situation—called **complete dominance**—the dominant allele has the same phenotypic effect whether present in one or two copies. But for some characters, the appearance of F_1 hybrids falls between the phenotypes of the two parental varieties, an effect called **incomplete dominance**. For instance, as **Figure 8.4A** illustrates, when red snapdragons are crossed with white snapdragons, all the F_1 hybrids have pink flowers. This third phenotype results from flowers of the heterozygote having less red pigment than the red homozygotes.

Incomplete dominance does *not* support the blending hypothesis described in Module 8.1, which would predict that the red and white traits could never be retrieved from the pink hybrids. As the Punnett square at the bottom of Figure 8.4A shows, the F_2 offspring appear in a phenotypic ratio of one red to two pink to one white, because the red and white alleles segregate during gamete formation in the pink F_1 hybrids. In incomplete dominance, the phenotypes of heterozygotes differ from the two homozygous varieties, and the genotypic ratio and the phenotypic ratio are both 1:2:1 in the F_2 generation.

We also see examples of incomplete dominance in humans. One case involves a recessive allele (h) that can cause hypercholesterolemia, dangerously high levels of cholesterol in the blood. Normal individuals are HH. Heterozygotes (Hh; about one in 500 people) have blood cholesterol levels about twice normal. They are unusually prone to atherosclerosis,



▲ **Figure 8.4A** Incomplete dominance in snapdragon flower color



▲ **Figure 8.4B** Incomplete dominance in human hypercholesterolemia

the blockage of arteries by cholesterol buildup in artery walls, and they may have heart attacks from blocked heart arteries by their mid-30s. This form of the disease can often be controlled through changes in diet and by taking statins, a class of medications that can significantly lower blood cholesterol. Hypercholesterolemia is even more serious in homozygous individuals (*hh*; about one in a million people).

Homozygotes have about five times the normal amount of blood cholesterol and may have heart attacks as early as age 2. Homozygous hypercholesterolemia is harder to treat; options include high doses of statin drugs, organ surgeries or transplants, or physically filtering lipids from the blood.

Figure 8.4B illustrates the molecular basis for hypercholesterolemia. The dominant allele (*H*), which normal individuals carry in duplicate (*HH*), specifies a cell-surface receptor protein called an LDL receptor. Low-density lipoprotein (LDL, sometimes called "bad cholesterol") is transported in the blood. In certain cells, the LDL receptors mop up excess LDL particles from the blood and promote their breakdown. This process helps prevent the accumulation of cholesterol in arteries. Without the receptors, lethal levels of LDL build up in the blood. Heterozygotes (*Hh*) have only half the normal number of LDL receptors, and homozygous recessives (*hh*) have none.

? **Why is a testcross unnecessary to determine whether a snapdragon with red flowers is homozygous or heterozygous?**

Because the homozygotes and heterozygotes differ in phenotype: red flowers for the dominant homozygote and pink flowers for the heterozygote.

The Chromosomal Basis of Inheritance

8.5 Chromosome behavior accounts for Mendel's laws

Mendel published his results in 1866, but not until long after he died did biologists understand the significance of his work. Cell biologists worked out the processes of mitosis and meiosis in the late 1800s (see Chapter 7 to review these processes). Then, around 1900, researchers began to notice parallels between the behavior of chromosomes and the behavior of Mendel's heritable factors. Eventually, one of biology's most important concepts emerged. By combining these observations, the **chromosome theory of inheritance** states that genes occupy specific loci (positions) on chromosomes, and it is the chromosomes that undergo segregation and independent assortment during meiosis. Thus, it is the behavior of chromosomes during meiosis and fertilization that accounts for inheritance patterns.

We can see the chromosomal basis of Mendel's laws by following the fates of two genes during meiosis and fertilization in pea plants. In **Figure 8.5**, we show the genes for seed shape (alleles *R* and *r*) and seed color (*Y* and *y*) as black bars on different chromosomes. We will now follow the chromosomes to

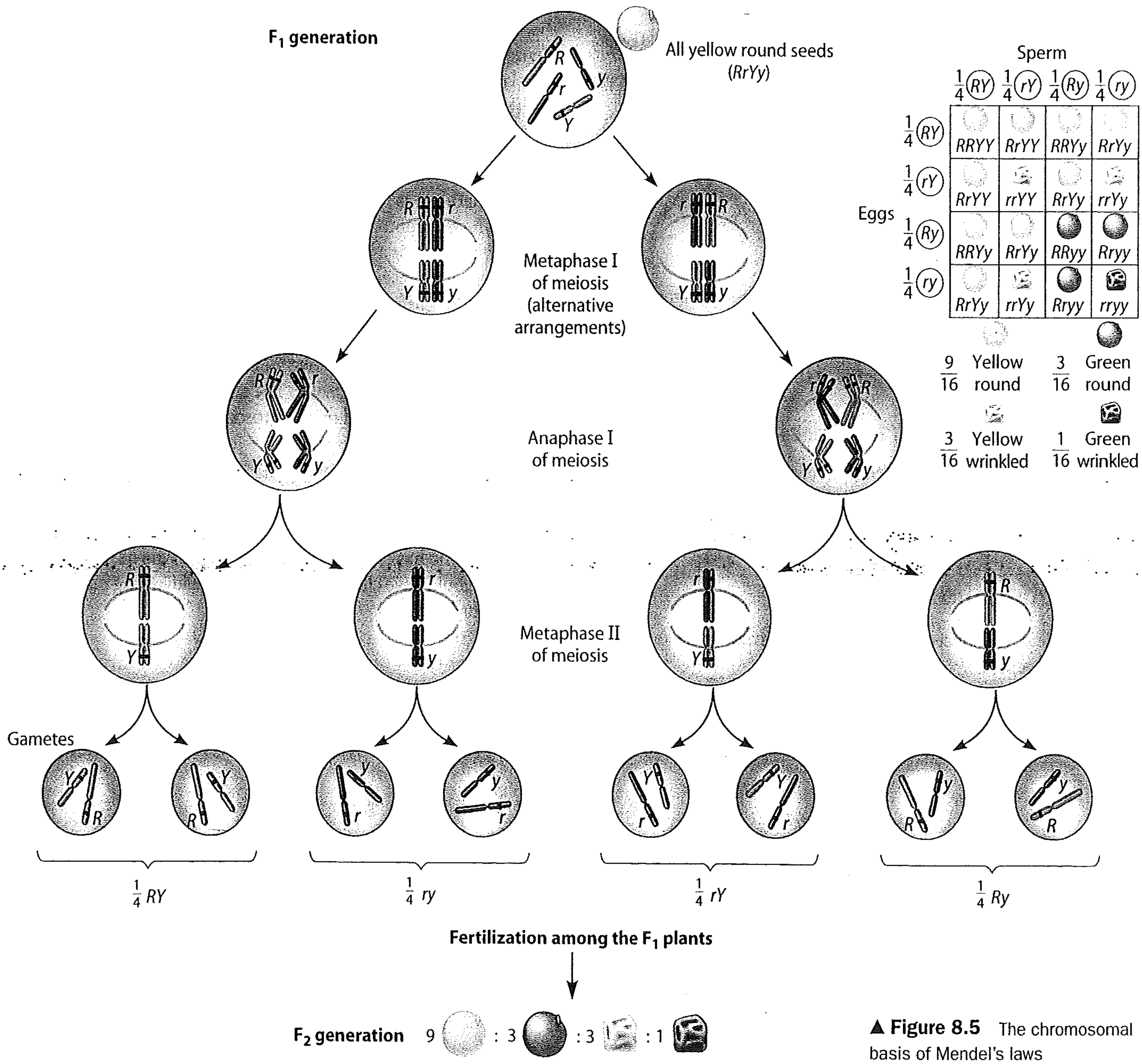
see how they account for the results of the dihybrid cross shown in the Punnett square. We start with the F_1 generation, in which all plants have the *RrYy* genotype. To simplify the diagram, we show only two of the seven pairs of pea chromosomes and three of the stages of meiosis: metaphase I, anaphase I, and metaphase II.

To see the chromosomal basis of the law of segregation (which states that pairs of alleles separate from each other during gamete formation via meiosis; see Module 8.3), let's follow just the homologous pair of long chromosomes, the ones carrying *R* and *r*, taking either the left or the right branch from the F_1 cell. Whichever arrangement the chromosomes assume at metaphase I, the two alleles segregate as the homologous chromosomes separate in anaphase I. And at the end of meiosis II, a single long chromosome ends up in each of the gametes. Fertilization then recombines the two alleles at random, resulting in F_2 offspring that are $\frac{1}{4}$ *RR*, $\frac{1}{2}$ *Rr*, and $\frac{1}{4}$ *rr*. The ratio of round to wrinkled phenotypes is thus 3:1 (12 round to 4 wrinkled), the ratio Mendel observed, as shown in the Punnett square in the figure.

To see the chromosomal basis of the law of independent assortment (which states that each pair of alleles sorts independently of other pairs of alleles during gamete formation), follow both the long and short (nonhomologous) chromosomes through the figure below. Two alternative, equally likely arrangements of tetrads can occur at metaphase I. The nonhomologous chromosomes (and their genes) assort independently, leading to four gamete genotypes. Random fertilization leads to the 9:3:3:1 phenotypic ratio in the F_2 generation.

? Which of Mendel's laws have their physical basis in the following phases of meiosis: (a) the orientation of homologous chromosome pairs in metaphase I; (b) the separation of homologs in anaphase I?

(a) The law of independent assortment; (b) the law of segregation.



▲ **Figure 8.5** The chromosomal basis of Mendel's laws

CHAPTER 8 REVIEW

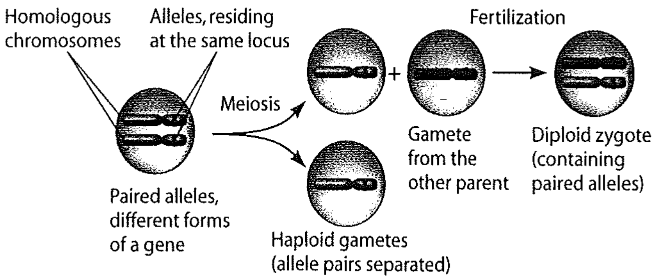
Reviewing the Concepts

Mendel's Laws (8.1–8.3)

8.1 The science of genetics has ancient roots.

8.2 Experimental genetics began in an abbey garden. The science of genetics began with Gregor Mendel's quantitative experiments. Mendel crossed pea plants and traced traits from generation to generation. He hypothesized that there are alternative versions of genes (alleles), the units that determine heritable traits.

8.3 Mendel's law of segregation describes the inheritance of a single character. Mendel's law of segregation predicts that each set of alleles will separate as gametes are formed:



Variations on Mendel's Laws (8.4)

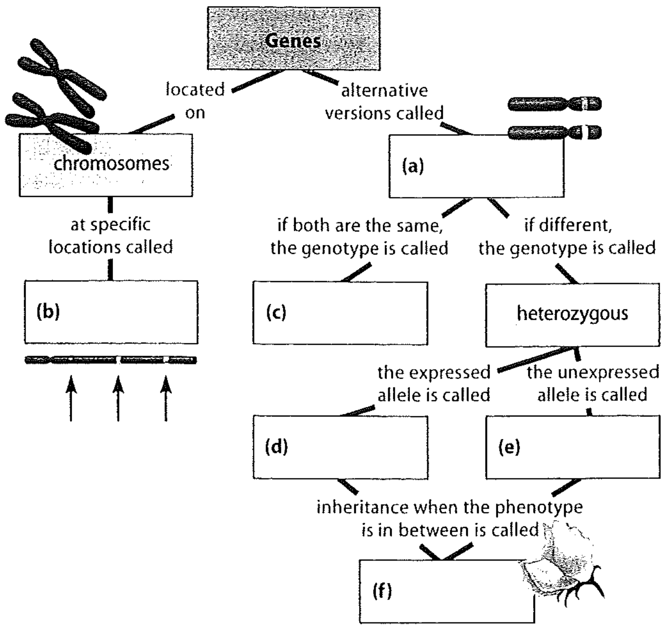
8.4 Incomplete dominance results in intermediate phenotypes. Mendel's laws are valid for all sexually reproducing species, but genotype often does not dictate phenotype in the simple way his laws describe, as shown in the figure at the top of the next column.

The Chromosomal Basis of Inheritance (8.5)

8.5 Chromosome behavior accounts for Mendel's laws. Genes are located on chromosomes, whose behavior during meiosis and fertilization accounts for inheritance patterns.

Connecting the Concepts

1. Complete this concept map to help you review some key concepts of genetics.



Testing Your Knowledge

Multiple Choice

2. Whether an allele is dominant or recessive depends on
   a. how common the allele is, relative to other alleles.
   b. whether it is inherited from the mother or the father.
   c. which chromosome it is on.
   d. whether it or another allele determines the phenotype when both are present.
   e. whether or not it is linked to other genes.

3. Two fruit flies with eyes of the usual red color are crossed, and their offspring are as follows: 77 red-eyed males, 71 ruby-eyed males, 152 red-eyed females. The allele for ruby eyes is
   a. autosomal (carried on an autosome) and dominant.
   b. autosomal and recessive.
   c. sex-linked and dominant.
   d. sex-linked and recessive.
   e. impossible to determine without more information.

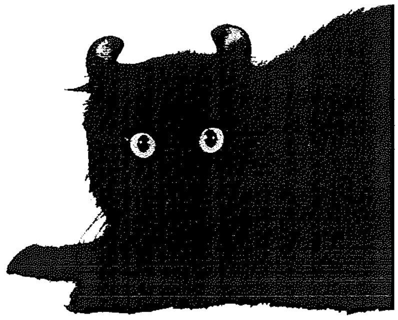
4. A man who has type B blood and a woman who has type A blood could have children of which of the following phenotypes?
   a. A or B only
   b. AB only
   c. AB or O
   d. A, B, or O
   e. A, B, AB, or O

Additional Genetics Problems

5. In fruit flies, the genes for wing shape and body stripes are linked. In a fly whose genotype is *WwSs*, *W* is linked to *S*, and *w* is linked to *s*. Show how this fly can produce gametes containing four different combinations of alleles. Which are parental-type gametes? Which are recombinant gametes? How are the recombinants produced?
6. Adult height in humans is at least partially hereditary; tall parents tend to have tall children. But humans come in a range of sizes, not just tall and short. Which extension of Mendel's model accounts for the hereditary variation in human height?
7. In rabbits, black hair depends on a dominant allele, *B*, and brown hair on a recessive allele, *b*. Short hair is due to a dominant allele, *S*, and long hair to a recessive allele, *s*. If a true-breeding black, short-haired male is mated with a brown, long-haired female, describe their offspring. What will be the genotypes of the offspring? If two of these F_1 rabbits are mated, what phenotypes would you expect among their offspring? In what proportions?
8. A fruit fly with a gray body and red eyes (genotype *BbPp*) is mated with a fly having a black body and purple eyes (genotype *bbpp*). What ratio of offspring would you expect if the body-color and eye-color genes are on different chromosomes (unlinked)? When this mating is actually carried out, most of the offspring look like the parents, but 3% have a gray body and purple eyes, and 3% have a black body and red eyes. Are these genes linked or unlinked? What is the recombination frequency?

Applying the Concepts

9. In 1981, a stray black cat with unusual rounded, curled-back ears was adopted by a family in Lakewood, California. Hundreds of descendants of this cat have since been born, and cat fanciers hope to develop the "curl" cat into a show breed. The curl allele is apparently dominant and autosomal (carried on an autosome). Suppose you owned the first curl cat and wanted to breed it to develop a true-breeding variety. Describe tests that would determine whether the curl gene is dominant or recessive and whether it is autosomal or sex-linked. Explain why you think your tests would be conclusive. Describe a test to determine that a cat is true-breeding.

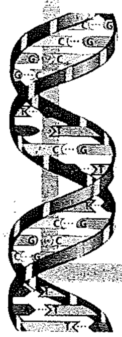


Answers to all questions can be found in Appendix 1.

CHAPTER

9 Molecular Biology of the Gene

BIG IDEAS

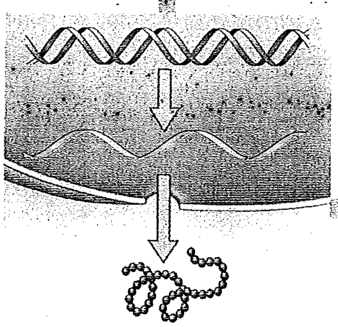


The Structure of the Genetic Material
(9.1–9.2)

A series of experiments established DNA as the molecule of heredity.

DNA Replication
(9.3)

Each DNA strand can serve as a template for another.



The Flow of Genetic Information from DNA to RNA to Protein
(9.4)

Genotype controls phenotype through the production of proteins.

The Structure of the Genetic Material

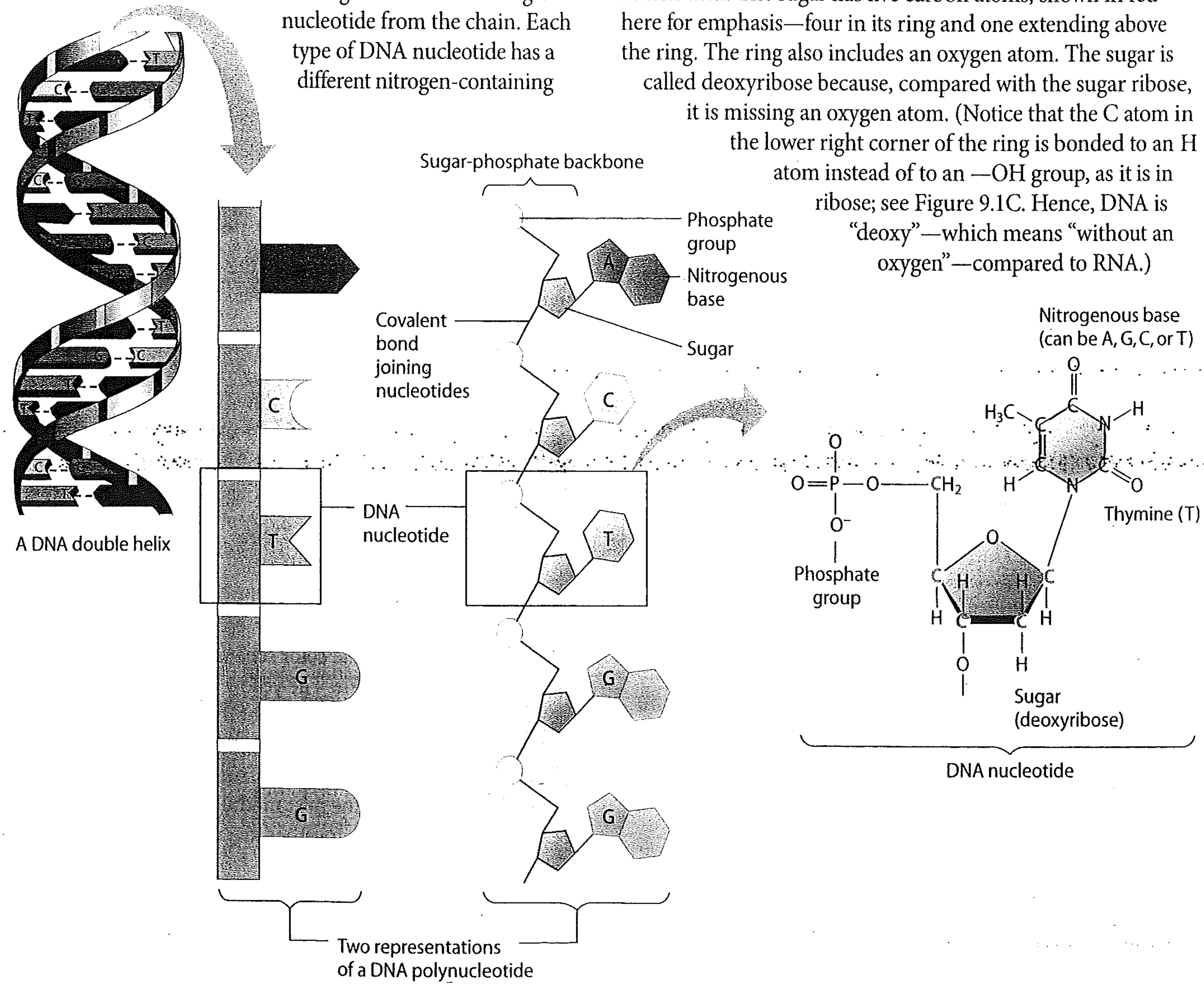
9.1 DNA and RNA are polymers of nucleotides

By the time Alfred Hershey and Martha Chase performed their experiments in 1952, much was already known about DNA. Scientists had identified all its atoms and knew how they were covalently bonded to one another. What was not understood was the specific arrangement of atoms that gave DNA its unique properties—the capacity to store genetic information, copy it, and pass it from generation to generation. However, only one year after Hershey and Chase published their results, scientists figured out the three-dimensional structure of DNA and the basic strategy of how it works. We will examine that momentous discovery in Module 9.2, but first, let's look at the underlying chemical structure of DNA and its chemical cousin RNA.

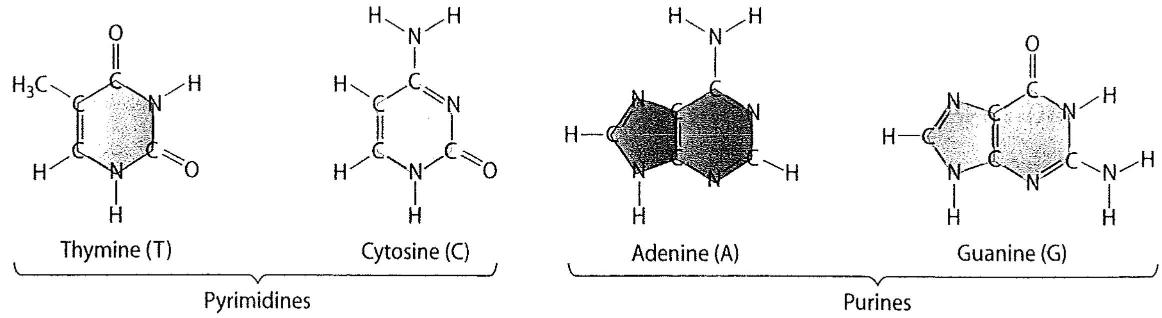
Recall from Module 2.13 that DNA and RNA are nucleic acids, consisting of long chains (polymers) of chemical units (monomers) called **nucleotides. Figure 9.1A** shows four representations of various parts of the same molecule. At left is a view of a DNA double helix. One of the strands is opened up (center) to show two different views of an individual DNA **polynucleotide**, a nucleotide polymer (chain). The view on the far right zooms into a single nucleotide from the chain. Each type of DNA nucleotide has a different nitrogen-containing base: adenine (A), cytosine (C), thymine (T), or guanine (G). Because nucleotides can occur in a polynucleotide in any sequence and polynucleotides vary in length from long to very long, the number of possible polynucleotides is enormous. The chain shown in this figure has the sequence ACTGG, only one of many possible arrangements of the four types of nucleotides that make up DNA.

Looking more closely at our polynucleotide, we see in the center of Figure 9.1A that each nucleotide consists of three components: a nitrogenous base (in DNA: A, C, T, or G), a sugar (blue), and a phosphate group (yellow). The nucleotides are joined to one another by covalent bonds between the sugar of one nucleotide and the phosphate of the next. This results in a **sugar-phosphate backbone**, a repeating pattern of sugar-phosphate-sugar-phosphate. The nitrogenous bases are arranged like ribs that project from the backbone.

Examining a single nucleotide in even more detail (on the right in Figure 9.1A), you can see the chemical structure of its three components. The phosphate group has a phosphorus atom (P) at its center and is the source of the word *acid* in *nucleic acid*. The sugar has five carbon atoms, shown in red here for emphasis—four in its ring and one extending above the ring. The ring also includes an oxygen atom. The sugar is called deoxyribose because, compared with the sugar ribose, it is missing an oxygen atom. (Notice that the C atom in the lower right corner of the ring is bonded to an H atom instead of to an —OH group, as it is in ribose; see Figure 9.1C. Hence, DNA is "deoxy"—which means "without an oxygen"—compared to RNA.)



▲ **Figure 9.1A** The structure of a DNA polynucleotide



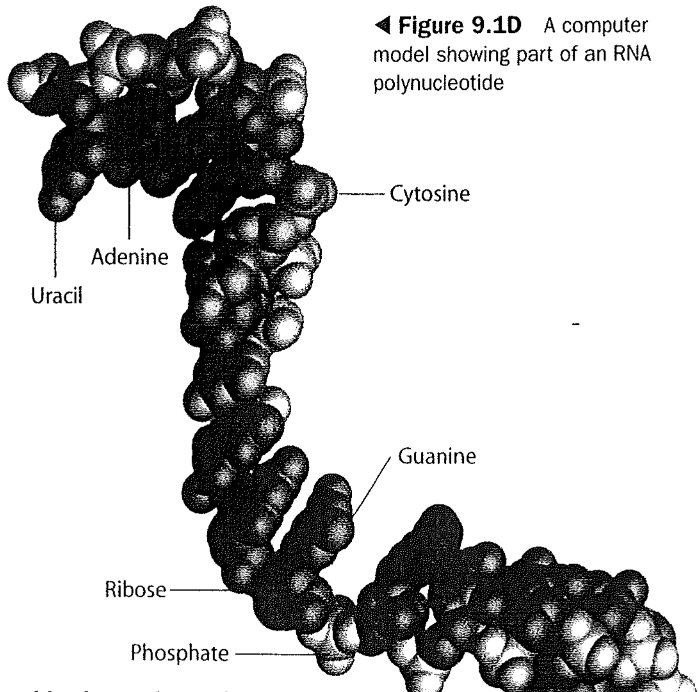
▲ **Figure 9.1B** The nitrogenous bases of DNA

The full name for DNA is **deoxyribonucleic acid**, with the *nucleic* portion of the word referring to DNA's location in the nuclei of eukaryotic cells. Each nitrogenous base (thymine, in our example at the right in Figure 9.1A) has a single or double ring consisting of nitrogen and carbon atoms with various functional groups attached. Recall from Module 2.2 that a functional group is a chemical group that affects a molecule's function by participating in specific chemical reactions. In the case of DNA, the main role of the functional groups is to determine which other kind of bases each base can hydrogen-bond with. For example, the NH_2 group hanging off cytosine is capable of forming a hydrogen bond to the C=O group hanging off guanine, but not with the NH_2 group protruding from adenine. The chemical groups of the bases are therefore responsible for DNA's most important property, which you will learn more about in the next module. In contrast to the acidic phosphate group, nitrogenous bases are basic, hence their name.

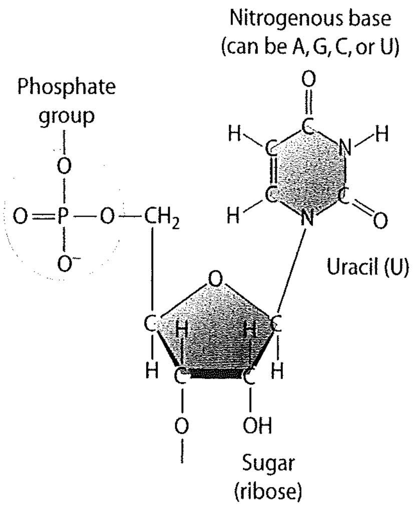
The four nucleotides found in DNA differ only in the structure of their nitrogenous bases **(Figure 9.1B)**. At this point, the structural details are not as important as the fact that the bases are of two types. **Thymine** (**T**) and **cytosine** (**C**) are single-ring structures called pyrimidines. **Adenine** (**A**) and **guanine** (**G**) are larger, double-ring structures called purines. The one-letter abbreviations can be used either for the bases alone or for the nucleotides containing them.

What about RNA **(Figure 9.1C)**? As its name—ribonucleic acid—implies, its sugar is ribose rather than deoxyribose. Notice the ribose in the RNA nucleotide in Figure 9.1C; unlike deoxyribose, the sugar ring has an —OH group attached to the C atom at its lower-right corner. Another difference between RNA and DNA is that instead of thymine, RNA has a nitrogenous base called **uracil** (**U**). (You can see the structure of uracil in Figure 9.1C; it is very similar to thymine.) Except for the presence of ribose and uracil, an RNA polynucleotide chain is identical to a DNA polynucleotide chain. **Figure 9.1D** is a computer graphic of a piece of RNA polynucleotide about 20 nucleotides long. In this 3-D view, each sphere represents an atom, and notice that the color scheme is the same as in the other figures in this module. The yellow phosphate groups and blue ribose sugars make it easy to spot the sugar-phosphate backbone.

In this module, we reviewed the structure of the nucleic acids DNA and RNA. In the next module, we'll see how two DNA polynucleotides join together in a molecule of DNA.



◀ **Figure 9.1D** A computer model showing part of an RNA polynucleotide



▲ **Figure 9.1C** An RNA nucleotide

? Compare and contrast DNA and RNA polynucleotides.

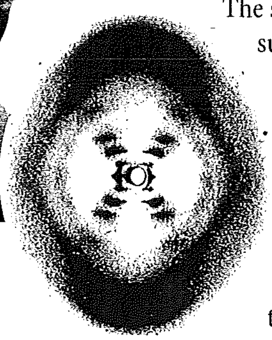
Both are polymers of nucleotides consisting of a sugar, a nitrogenous base, and a phosphate. In RNA, the sugar is ribose; in DNA, it is deoxyribose. Both RNA and DNA have the bases A, G, and C, but DNA has a T and RNA has a U.

SCIENTIFIC DISCOVERY

9.2 DNA is a double-stranded helix

After the 1952 Hershey-Chase experiment convinced most biologists that DNA was the material that stored genetic information, a race was on to determine how the structure of this molecule could account for its role in heredity. By that time, the arrangement of covalent bonds in a nucleic acid polymer was well established, and researchers focused on discovering the three-dimensional shape of DNA. First to the finish line were two scientists who were relatively unknown at the time—American James D. Watson and Englishman Francis Crick.

The brief but celebrated partnership that solved the puzzle of DNA structure began soon after Watson, a 23-year-old newly minted Ph.D., journeyed to Cambridge University in England, where the more senior Crick was studying protein structure with a technique called X-ray crystallography. While visiting the laboratory of Maurice Wilkins at King's College in London, Watson saw an X-ray crystallographic image of DNA produced by Wilkins's colleague Rosalind Franklin **(Figure 9.2A)**. A careful study of the image enabled Watson to deduce the basic shape of DNA to be a helix with a uniform diameter of 2 nanometers (nm), with its nitrogenous bases stacked about one-third of a nanometer apart. (For comparison, the plasma membrane of a cell is about 8 nm thick.) The diameter of the helix suggested that it was made up of two polynucleotide strands, a **double helix**.



▲ **Figure 9.2A** Rosalind Franklin and her X-ray image of DNA

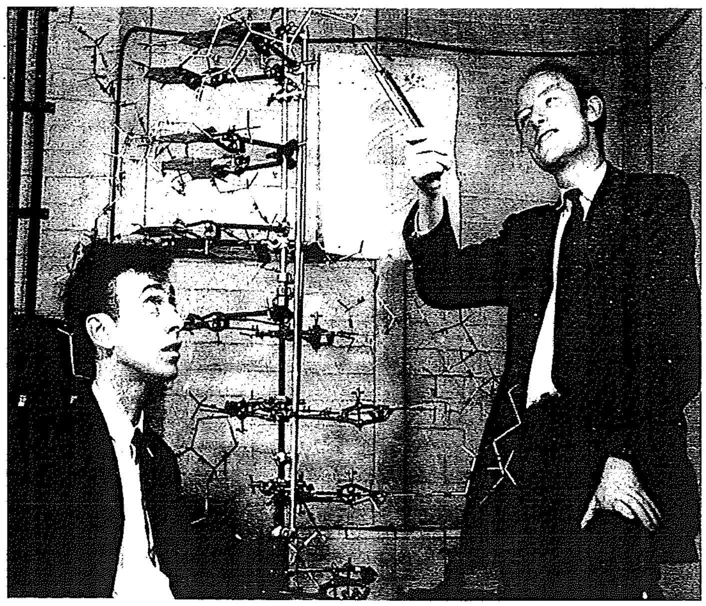
Watson and Crick began trying to construct a wire model of a double helix that would conform both to Franklin's data and to what was then known about the chemistry of DNA **(Figure 9.2B)**. They had concluded that the sugar-phosphate backbones must be on the outside of the double helix, forcing the nitrogenous bases to swivel to the interior of the molecule. But how were the bases arranged in the interior of the double helix?

At first, Watson and Crick imagined that the bases paired like with like—for example, A with A and C with C. But that kind of pairing did not fit the X-ray data, which suggested that the DNA molecule has a uniform diameter. An A-A pair, with two double-ring bases, would be almost twice as wide as a C-C pair. It soon became apparent that a double-ringed base (purine) must always be paired with a single-ringed base (pyrimidine) on the opposite strand. Moreover, Watson and Crick realized that the individual structures of the bases dictated the pairings even more specifically. As discussed in the previous module, each base has functional groups protruding from its six-sided ring that can best form hydrogen bonds with one appropriate partner. Adenine can best form hydrogen bonds with thymine, and guanine with cytosine. In the biologist's shorthand, A pairs with T, and G pairs with C. A is also said to be "complementary" to T, and G to C.

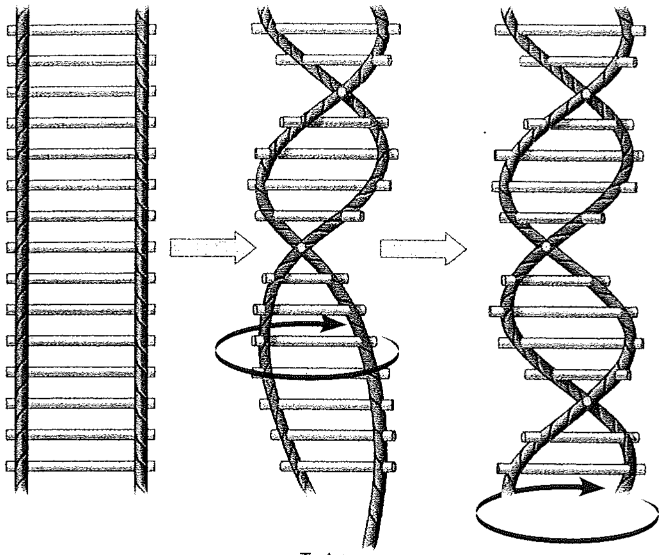
Watson and Crick's pairing scheme not only fit what was known about the physical attributes and chemical bonding of DNA, but also explained some data obtained several years earlier by American biochemist Erwin Chargaff. Chargaff had discovered that the amount of adenine in the DNA of any one species was equal to the amount of thymine and that the amount of guanine was equal to that of cytosine. Chargaff's rules, as they are called, are explained by the fact that A on one of DNA's polynucleotide chains always pairs with T on the other polynucleotide chain, and G on one chain pairs only with C on the other chain.

You can picture the model of the DNA double helix proposed by Watson and Crick as a rope ladder with wooden rungs, with the ladder twisting into a spiral **(Figure 9.2C)**. The side ropes are the equivalent of the sugar-phosphate backbones, and the rungs represent pairs of nitrogenous bases joined by hydrogen bonds.

Figure 9.2D shows three representations of the double helix. The shapes of the base symbols in the ribbonlike diagram on the left indicate the bases' complementarity; notice that the shape of any kind of base matches only one other kind of base. In the center of the diagram is an atomic-level version showing four base pairs, with the helix untwisted and the hydrogen bonds specified by dotted lines. Notice that a C-G base pair has functional groups that form three hydrogen bonds, while an A-T base pair has functional groups that



▲ **Figure 9.2B** Watson and Crick in 1953 with their model of the DNA double helix



▲ **Figure 9.2C** A rope ladder model for the double helix

form two hydrogen bonds. This difference means that C-G base pairs are somewhat stronger than A-T base pairs. You can see that the two sugar-phosphate backbones of the double helix are oriented in opposite directions. (Notice that the sugars on the two strands are upside down with respect to each other.) On the right is a computer graphic showing most of the atoms of part of a double helix. The atoms that compose the deoxyribose sugars are shown as blue, phosphate groups as yellow, and nitrogenous bases as shades of green and orange.

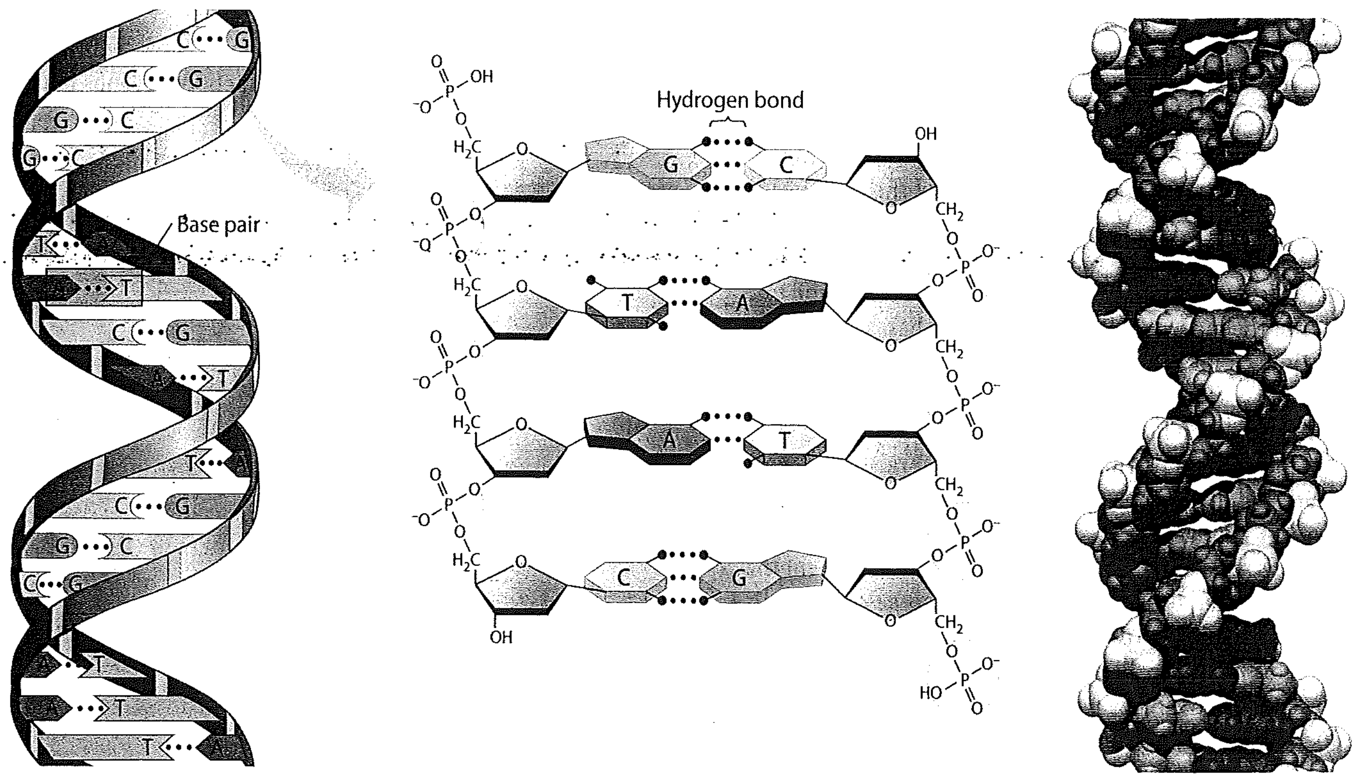
Although the Watson-Crick base-pairing rules dictate the side-by-side combinations of nitrogenous bases that form the rungs of the double helix, they place no restrictions on the sequence of nucleotides along the length of a DNA strand. In fact, the sequence of bases can vary in countless ways, and each gene has a unique order of nucleotides, or base sequence.

In April 1953, Watson and Crick rocked the scientific world with a succinct paper explaining their molecular model for DNA in the journal *Nature.* In 1962, Watson, Crick, and Wilkins received the Nobel Prize for their work. (Rosalind Franklin probably would have received the prize as well but for her death from cancer in 1958; Nobel Prizes are never awarded posthumously.) Few milestones in the history of biology have had as broad an impact as the discovery of the double helix, with its A-T and C-G base pairing.

The Watson-Crick model gave new meaning to the words *genes* and *chromosomes*—and to the chromosome theory of inheritance (see Module 8.5). With a complete picture of DNA, we can see that the genetic information in a chromosome must be encoded in the nucleotide sequence of the molecule. One powerful aspect of the Watson-Crick model is that the structure of DNA suggests a molecular explanation for genetic inheritance, as we will see in the next module.

? **Along one strand of a double helix is the nucleotide sequence GGCATAGGT. What is the complementary sequence for the other DNA strand?**

CCGTATCCA



▲ **Figure 9.2D** Three representations of DNA

DNA Replication

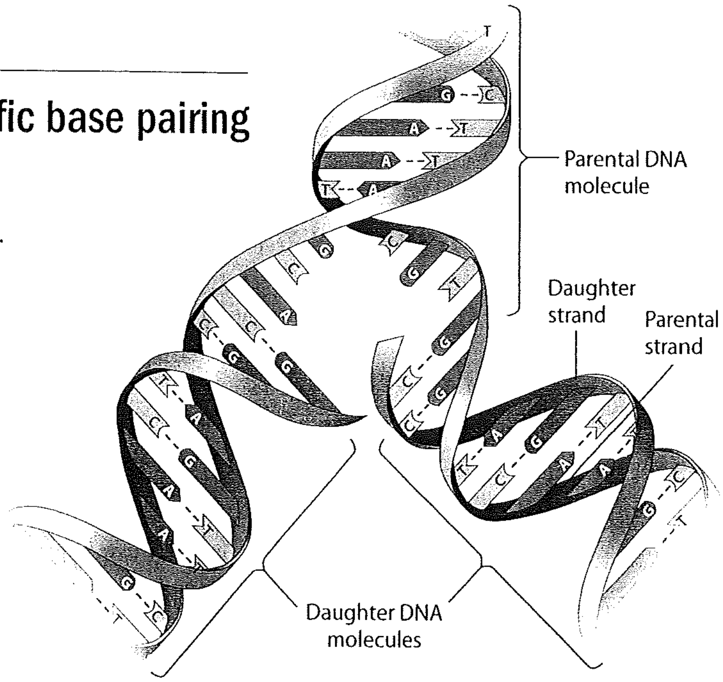
9.3 DNA replication depends on specific base pairing

One of biology's overarching themes—the relationship between structure and function—is evident in the double helix. The idea that there is specific pairing of bases in DNA was the flash of inspiration that led Watson and Crick to the correct structure of the double helix. At the same time, they saw the functional significance of the base-pairing rules. They ended their classic 1953 paper with this statement: "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material."

The logic behind the Watson-Crick proposal for how DNA is copied—by specific pairing of complementary bases—is quite simple. You can see this by covering one of the strands in the parental DNA molecule in **Figure 9.3A**. You can determine the sequence of bases in the covered strand by applying the base-pairing rules to the unmasked strand: A pairs with T (and T with A), and G pairs with C (and C with G).

Watson and Crick predicted that a cell applies the same rules when copying its genes. As shown in Figure 9.3A, the two strands of parental DNA (blue) separate. Each then becomes a template for the assembly of a complementary strand from a supply of free nucleotides (gray) that is always available within the nucleus. The nucleotides line up one at a time along the template strand in accordance with the base-pairing rules. Enzymes link the nucleotides to form the new DNA strands. The completed new molecules, identical to the parental molecule, are known as daughter DNA (although no gender should be inferred).

Watson and Crick's model predicts that when a double helix replicates, each of the two daughter molecules will have one old strand, which was part of the parental molecule, and one newly created strand. This model for DNA replication is known as the **semiconservative model** because half of the parental molecule is maintained (conserved) in each daughter molecule. The semiconservative model of replication was confirmed by experiments performed in the 1950s.



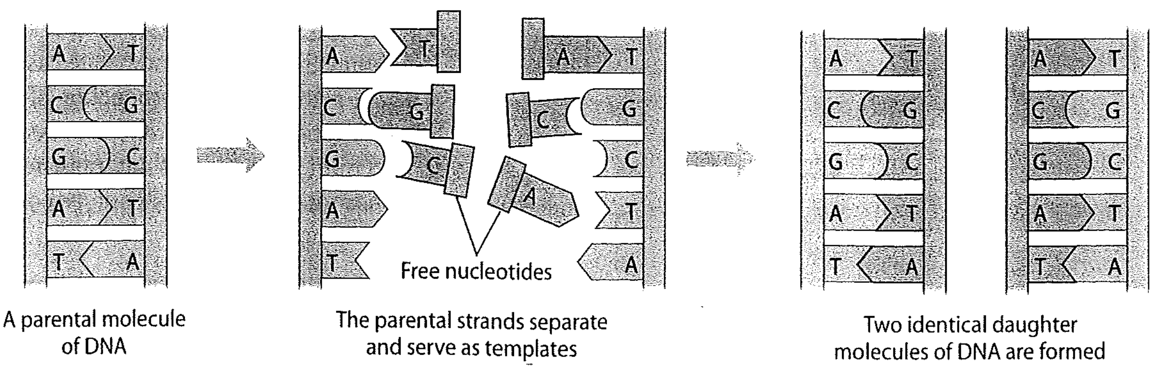
▲ **Figure 9.3B** The untwisting and replication of DNA

Although the general mechanism of DNA replication is conceptually simple, the actual process is complex, requiring the coordination of more than a dozen enzymes and other proteins. Some of the complexity arises from the need for the helical DNA molecule to untwist as it replicates and for the two new strands to be made roughly simultaneously **(Figure 9.3B)**. Another challenge is the speed of the process. *E. coli*, with about 4.6 million DNA base pairs, can copy its entire genome in less than an hour. Humans, with over 6 billion base pairs in 46 diploid chromosomes, require only a few hours. And yet, the process is amazingly accurate; typically, only about one DNA nucleotide per several billion is incorrectly paired. In the next module, we take a closer look at the mechanisms of DNA replication that allow it to proceed with such speed and accuracy.

? How does complementary base pairing make possible the replication of DNA?

When the two strands of the double helix separate, free nucleotides can base-pair along each strand, leading to the synthesis of new complementary strands.

▶ **Figure 9.3A** A template model for DNA replication



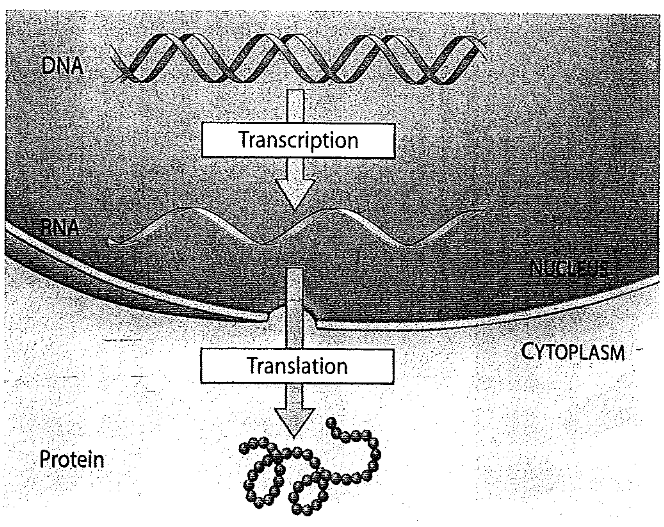
The Flow of Genetic Information from DNA to RNA to Protein

9.4 The DNA genotype is expressed as proteins, which provide the molecular basis for phenotypic traits

With our knowledge of DNA, we can now define genotype and phenotype more precisely than we did in Chapter 8. An organism's genotype, its genetic makeup, is the heritable information contained in its DNA. The phenotype is the organism's physical traits. So what is the molecular connection between genotype and phenotype?

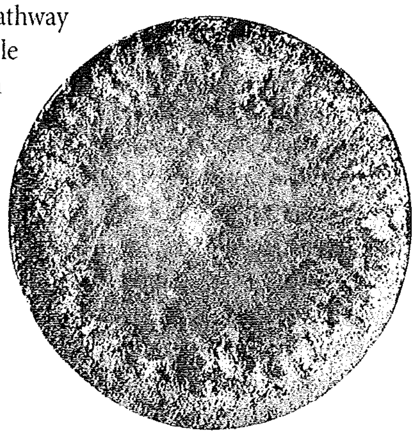
The answer is that the DNA inherited by an organism specifies traits by dictating the synthesis of proteins. In other words, proteins are the links between the genotype and the phenotype. However, a gene does not build a protein directly. Rather, a gene dispatches instructions in the form of RNA, which in turn programs protein synthesis. This fundamental concept in biology, termed the "central dogma" by Francis Crick, is summarized in **Figure 9.4A**. The molecular "chain of command" is from DNA in the nucleus of the cell to RNA to protein synthesis in the cytoplasm. The two main stages are **transcription**, the synthesis of RNA under the direction of DNA, and **translation**, the synthesis of protein under the direction of RNA.

The relationship between genes and proteins was first proposed in 1909, when English physician Archibald Garrod suggested that genes dictate phenotypes through enzymes, the proteins that catalyze chemical reactions. Garrod hypothesized that an inherited disease reflects a person's inability to make a particular enzyme, and he referred to such diseases as "inborn errors of metabolism." He gave as one example the hereditary condition called alkaptonuria, in which the urine is dark because it contains a chemical called alkapton. Garrod reasoned that individuals without the disorder have an enzyme that breaks down alkapton, whereas alkaptonuric individuals cannot make the enzyme. Garrod's hypothesis was ahead of its time, but research conducted decades later proved him right. In the intervening years, biochemists accumulated evidence that cells make and break down biologically important molecules via metabolic pathways, as in the synthesis of an amino acid or the breakdown of a sugar. As we described in Unit I, each step in a metabolic pathway is catalyzed by a specific enzyme. Therefore, individuals lacking one of the enzymes for a pathway are unable to complete it.



▲ **Figure 9.4A** The flow of genetic information in a eukaryotic cell

The major breakthrough in demonstrating the relationship between genes and enzymes came in the 1940s from the work of American geneticists George Beadle and Edward Tatum with the bread mold *Neurospora crassa* (**Figure 9.4B**). Beadle and Tatum studied strains of the mold that were unable to grow on a simple growth medium. Each of these so-called nutritional mutants turned out to lack an enzyme in a metabolic pathway that produced some molecule the mold needed, such as an amino acid. Beadle and Tatum also showed that each mutant was defective in a single gene. This result suggested the one gene–one enzyme hypothesis—the idea that the function of a gene is to dictate the production of a specific enzyme.



▲ **Figure 9.4B** The bread mold *Neurospora crassa* growing in a culture dish

The one gene–one enzyme hypothesis has been amply confirmed, but with important modifications. First, it was extended beyond enzymes to include *all* types of proteins. For example, keratin (the structural protein of hair) and the hormone insulin are two examples of proteins that are not enzymes. So biologists began to think in terms of one gene–one protein. However, many proteins are made from two or more polypeptide chains, with each polypeptide specified by its own gene. For example, hemoglobin, the oxygen-transporting protein in your blood, is built from two kinds of polypeptides, encoded by two different genes. Thus, Beadle and Tatum's hypothesis is now stated as follows: The function of a gene is to dictate the production of a polypeptide. Even this description is not entirely accurate, in that the RNA transcribed from some genes is not translated. The flow of information from genotype to phenotype continues to be an active research area.

? What are the functions of transcription and translation?

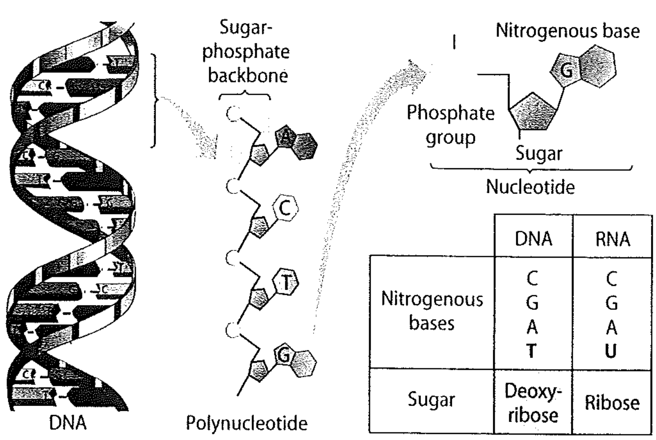
Transcription is the transfer of information from DNA to RNA. Translation is the use of the information in RNA to make a polypeptide.

CHAPTER 9 REVIEW

Reviewing the Concepts

The Structure of the Genetic Material (9.1–9.2)

9.1 DNA and RNA are polymers of nucleotides.



	DNA	RNA
Nitrogenous bases	C G A T	C G A U
Sugar	Deoxyribose	Ribose

9.2 DNA is a double-stranded helix. Watson and Crick worked out the three-dimensional structure of DNA: two polynucleotide strands wrapped around each other in a double helix. Hydrogen bonds between bases hold the strands together. Each base pairs with a complementary partner: A with T, G with C.

DNA Replication (9.3)

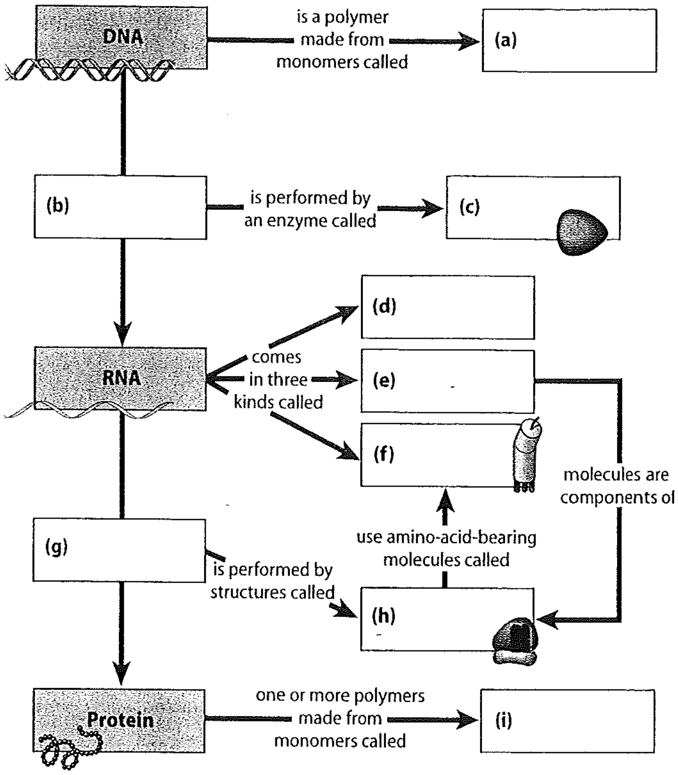
9.3 DNA replication depends on specific base pairing. DNA replication starts with the separation of DNA strands. Enzymes then use each strand as a template to assemble new nucleotides into a complementary strand.

The Flow of Genetic Information from DNA to RNA to Protein (9.4)

9.4 The DNA genotype is expressed as proteins, which provide the molecular basis for phenotypic traits. The DNA of a gene—a linear sequence of many nucleotides—is transcribed into RNA, which is translated into a polypeptide.

Connecting the Concepts

1. Check your understanding of the flow of genetic information through a cell by filling in the blanks.



Testing Your Knowledge

Multiple Choice

2. A geneticist found that a particular mutation had no effect on the polypeptide encoded by a gene. This mutation probably involved
   a. deletion of one nucleotide.
   b. alteration of the start codon.
   c. insertion of one nucleotide.
   d. deletion of the entire gene.
   e. substitution of one nucleotide.

3. Which of the following correctly ranks the structures in order of size, from largest to smallest?
   a. gene-chromosome-nucleotide-codon
   b. chromosome-gene-codon-nucleotide
   c. nucleotide-chromosome-gene-codon
   d. chromosome-nucleotide-gene-codon
   e. gene-chromosome-codon-nucleotide

Describing, Comparing, and Explaining

4. Describe the process of DNA replication: the ingredients needed, the steps in the process, and the final product.

5. Describe the process by which the information in a eukaryotic gene is transcribed and translated into a protein. Correctly use these words in your description: tRNA, amino acid, start codon, transcription, RNA splicing, exons, introns, mRNA, gene, codon, RNA polymerase, ribosome, translation, anticodon, peptide bond, stop codon.

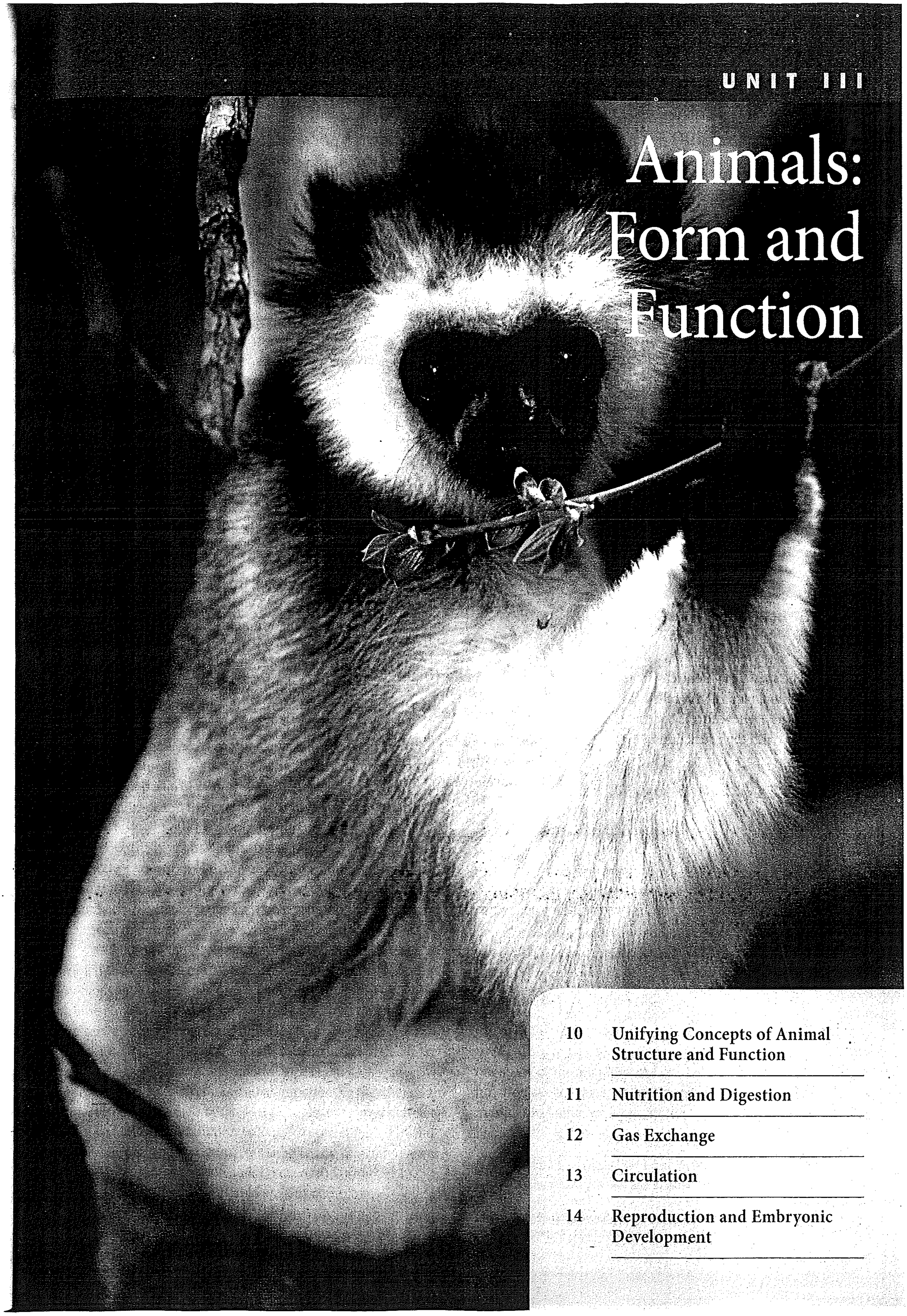
Applying the Concepts

6. A cell containing a single chromosome is placed in a medium containing radioactive phosphate so that any new DNA strands formed by DNA replication will be radioactive. The cell replicates its DNA and divides. Then the daughter cells (still in the radioactive medium) replicate their DNA and divide, and a total of four cells are present. Sketch the DNA molecules in all four cells, showing a normal (nonradioactive) DNA strand as a solid line and a radioactive DNA strand as a dashed line.

Answers to all questions can be found in Appendix 1.

UNIT III

Animals: Form and Function

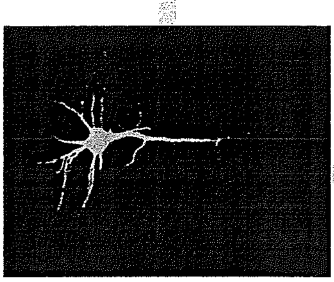


C H A P T E R

10

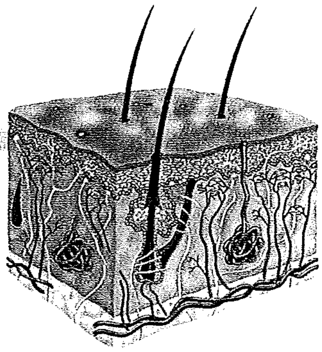
Unifying Concepts of Animal Structure and Function

BIG IDEAS



Structure and Function in Animal Tissues
(10.1–10.6)

The structural hierarchy in an animal begins with cells and tissues, whose forms correlate with their functions.



Organs and Organ Systems
(10.7–10.8)

Tissues are arranged into organs, which may be functionally coordinated in organ systems.

Structure and Function in Animal Tissues

10.1 Structure fits function at all levels of organization in the animal body

When discussing structure and function, biologists distinguish anatomy from physiology. **Anatomy** is the study of the form of an organism's structures; **physiology** is the study of the functions of those structures. A biologist interested in anatomy, for instance, might focus on the arrangement of muscles and bones in a gecko's legs. A physiologist might study how a gecko's muscles function. Despite their different approaches, both scientists are working toward a better understanding of the connection between structure and function, such as how the structural adaptations of the hairs on its toes give the gecko its remarkable ability to walk on walls.

Structure in the living world is organized in hierarchical levels. We followed the progression from molecules to cells in Unit I. Now, let's trace the hierarchy in animals from cells to organisms. As we discussed in Module 1.2, emergent properties—novel properties that were not present at the preceding level of the hierarchy of life—arise as a result of the structural and functional organization of each level's component parts.

Figure 10.1 illustrates structural hierarchy in a ring-tailed lemur. **Part A** shows a single muscle cell in the lemur's heart. This cell's main function is to contract, and the stripes in the cell indicate the precise alignment of strands of proteins that perform that function. Each muscle cell is also branched, providing for multiple connections to other cells that ensure coordinated contractions of all the muscle cells in the heart.

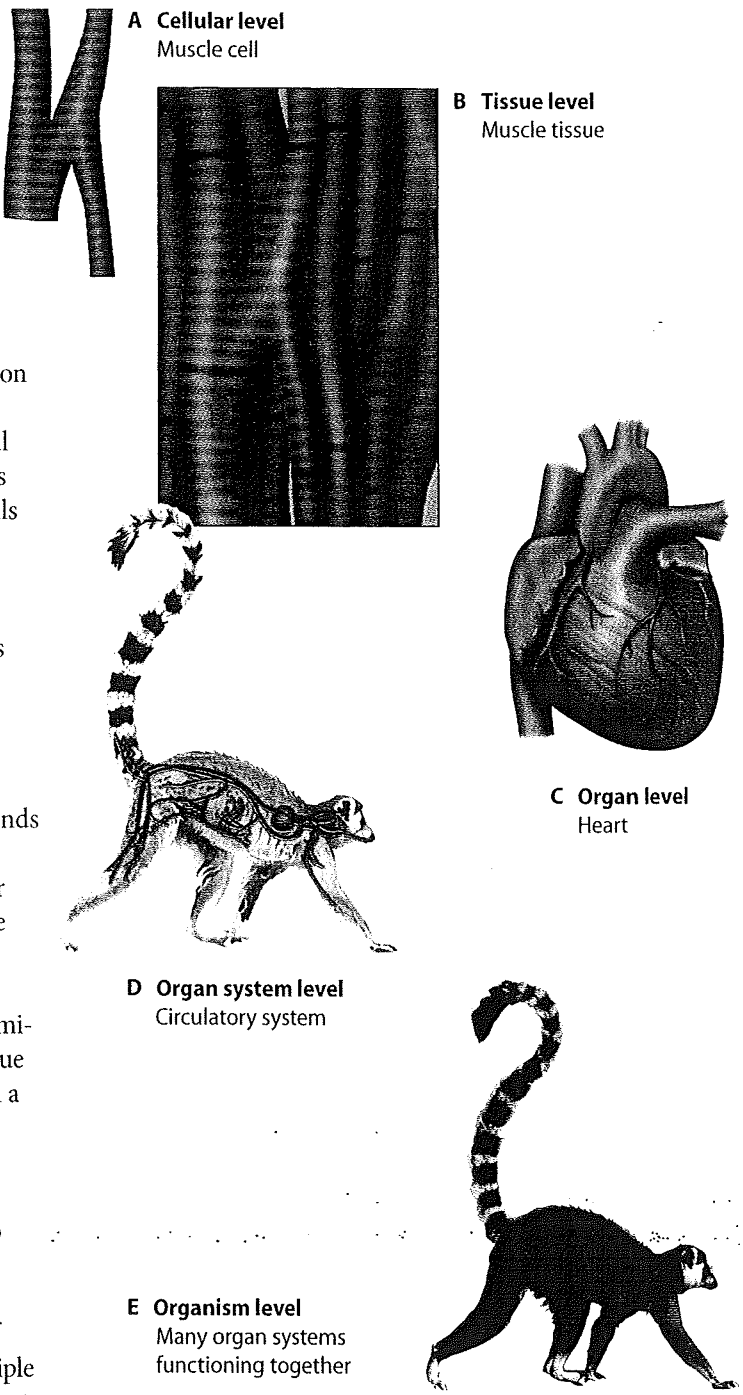
Together, these heart cells make up a tissue **(Part B)**, the second structural level. A **tissue** is an integrated group of similar cells that perform a common function. The cells of a tissue are specialized, and their structure enables them to perform a specific task—in this instance, coordinated contraction.

Part C, the heart itself, illustrates the organ level of the hierarchy. An **organ** is made up of two or more types of tissues that together perform a specific task. In addition to muscle tissue, the heart includes nervous, epithelial, and connective tissue.

Part D shows the circulatory system, the organ system of which the heart is a part. An **organ system** consists of multiple organs that together perform a vital body function. Other parts of the circulatory system include the blood and the blood vessels: arteries, veins, and capillaries.

In **Part E,** the lemur itself forms the final level of this hierarchy. An organism contains a number of organ systems, each specialized for certain tasks and all functioning together as an integrated, coordinated unit. For example, the lemur's circulatory system cannot function without oxygen supplied by the respiratory system and nutrients supplied by the digestive system. And it takes the coordination of several other organ systems to enable this animal to walk or climb trees.

The ability to climb trees or walls emerges from the specific arrangement of specialized structures. As we see throughout our study of the anatomy and physiology of animals, form fits function at each level of the structural hierarchy. In several modules to come, we focus on the tissue level of this biological hierarchy.



▲ **Figure 10.1** A structural hierarchy in a ring-tailed lemur

? Explain how the ability to pump blood is an emergent property of a heart, which is at the organ level of the biological hierarchy.

The specific structural organization and integration of the individual muscle, connective, epithelial, and nervous tissues of a heart enable the function of pumping blood.

10.2 Tissues are groups of cells with a common structure and function

In almost all animals, the cells of the body are organized into tissues. The term *tissue* is from a Latin word meaning "weave," and some tissues resemble woven cloth in that they consist of a meshwork of nonliving fibers and other extracellular substances surrounding living cells. Other tissues are held together by a sticky glue that coats the cells or by special junctions between adjacent plasma membranes. The structure of tissues relates to their specific functions.

The specialization of complex body parts such as organs and organ systems is largely based on varied combinations of a limited set of cells and tissue types. For example, your lungs and blood vessels have very distinct functions, but they are lined by tissues that are of the same basic type.

Your body is built from four main types of tissues: epithelial, connective, muscle, and nervous. We examine the structure and function of these tissue types in the next four modules.

? How is a tissue different from a cell and an organ?

Tissues are collections of similar cells that perform a common function. Several different tissue types usually produce the structure of an organ.

10.3 Epithelial tissue covers the body and lines its organs and cavities

Epithelial tissues, or epithelia (singular, *epithelium*), are sheets of closely packed cells that cover your body surface and line your internal organs and cavities. The tightly knit cells form a protective barrier and, in some cases, a surface for exchange with the fluid or air on the other side. One side of an epithelium is attached to a basal lamina, a dense mat of extracellular matrix consisting of fibrous proteins and sticky polysaccharides that separates the epithelium from the underlying tissues. The other side, called the apical surface, faces the outside of an organ or the inside of a tube or passageway.

Epithelial tissues are named according to the number of cell layers they have and according to the shape of the cells on their apical surface. A simple epithelium has a single layer of cells, whereas a stratified epithelium has multiple layers. A pseudostratified epithelium has a single layer but appears stratified because the cells vary in length. The shape of the cells may be squamous (flat like floor tiles), cuboidal (like dice), or columnar (like bricks on end). **Figure 10.3** shows examples of different types of epithelia. In each case, the pink color identifies the cells of the epithelium itself.

The structure of each type of epithelium fits its function. Simple squamous epithelium **(Part A)** is thin and leaky and thus suitable for exchanging materials by diffusion. You would find it lining your capillaries and the air sacs of your lungs.

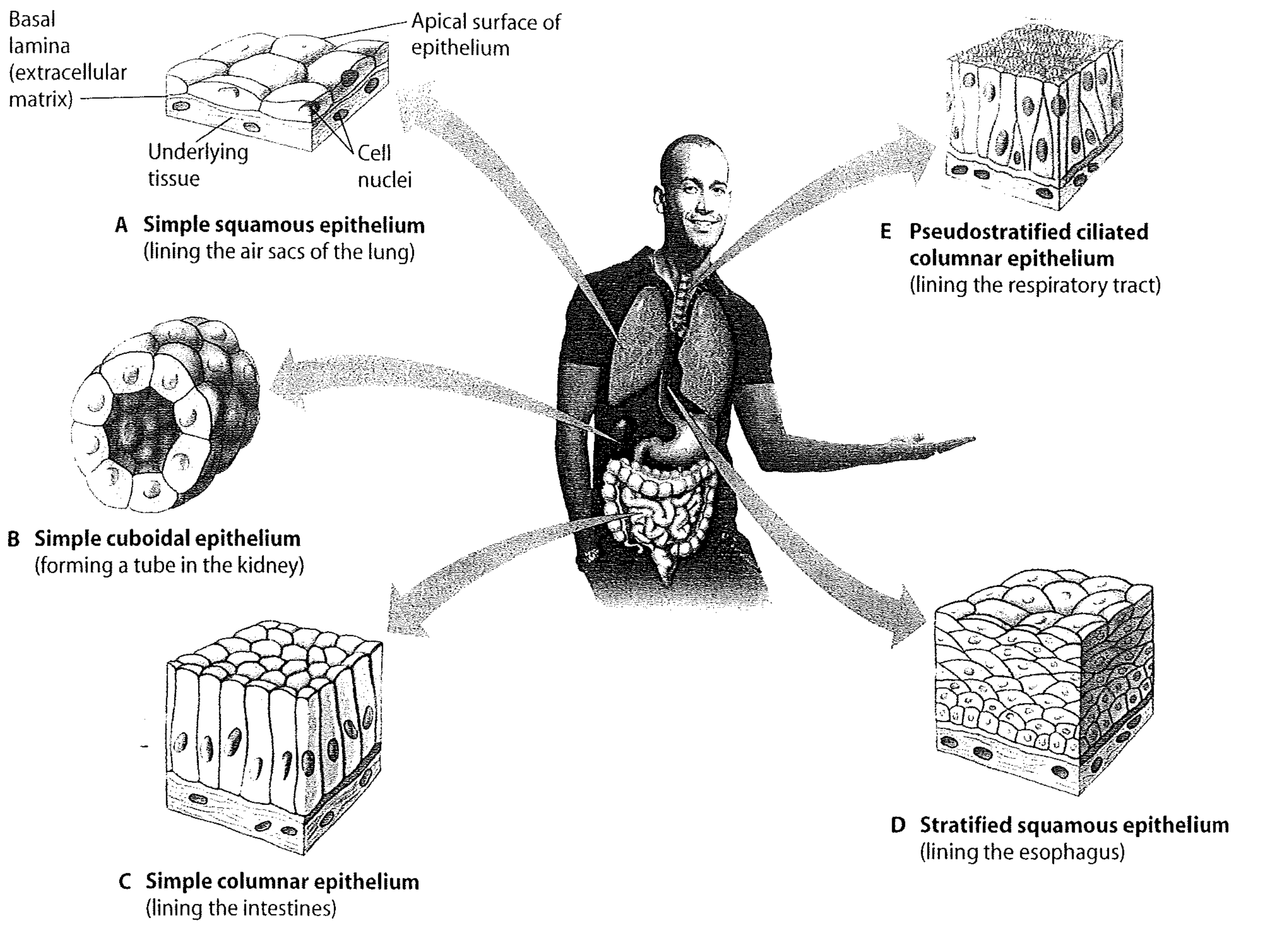
Both cuboidal and columnar epithelia have cells with a relatively large amount of cytoplasm, facilitating their role of secretion or absorption of materials. **Part B** shows a cuboidal epithelium forming a tube in the kidney. Such epithelia are also found in glands, such as the thyroid and salivary glands. A simple columnar epithelium **(Part C)** lines your intestines, where it secretes digestive juices and absorbs nutrients.

The many layers of the stratified squamous epithelium in **Part D** make it well suited for lining surfaces subject to abrasion, such as your outer skin and the linings of your mouth and esophagus. Stratified squamous epithelium regenerates rapidly by division of the cells near the basal lamina. New cells move toward the apical surface as older cells slough off.

The pseudostratified ciliated columnar epithelium in **Part E** forms a mucous membrane that lines portions of your respiratory tract and helps keep your lungs clean. Dust, pollen, and other particles are trapped in the mucus it secretes and then swept up and out of your respiratory tract by the beating of the cilia on its cells.

? Epithelial tissues are named according to the _______ of cells on their apical surface and the number of cell _______.

shape . . . layers.



▲ **Figure 10.3** Types of epithelial tissue

10.4 Connective tissue binds and supports other tissues

In contrast to epithelium, **connective tissue** consists of a sparse population of cells scattered throughout an extracellular material called a matrix. The cells produce and secrete the matrix, which usually consists of a web of fibers embedded in a liquid, jelly, or solid. Connective tissues may be grouped into six major types. **Figure 10.4** shows micrographs of each type and illustrates where each would be found in your arm, for example.

The most widespread connective tissue in your body is called **loose connective tissue (Part A)** because its matrix is a loose weave of fibers. Many of the fibers consist of the strong, ropelike protein collagen. Other fibers are more elastic, making the tissue resilient as well as strong. Loose connective tissue serves mainly to bind epithelia to underlying tissues and hold organs in place. In the figure, we show the loose connective tissue that lies directly under the skin.

Fibrous connective tissue (Part B) has densely packed parallel bundles of collagen fibers, an arrangement that maximizes its strength. This tissue forms tendons, which attach your muscles to bone, and ligaments, which connect your bones at joints.

Adipose tissue (Part C) stores fat in large, closely packed adipose cells held in a matrix of fibers. This tissue pads and insulates your body and stores energy. Each adipose cell contains a large fat droplet that swells when fat is stored and shrinks when fat is used as fuel.

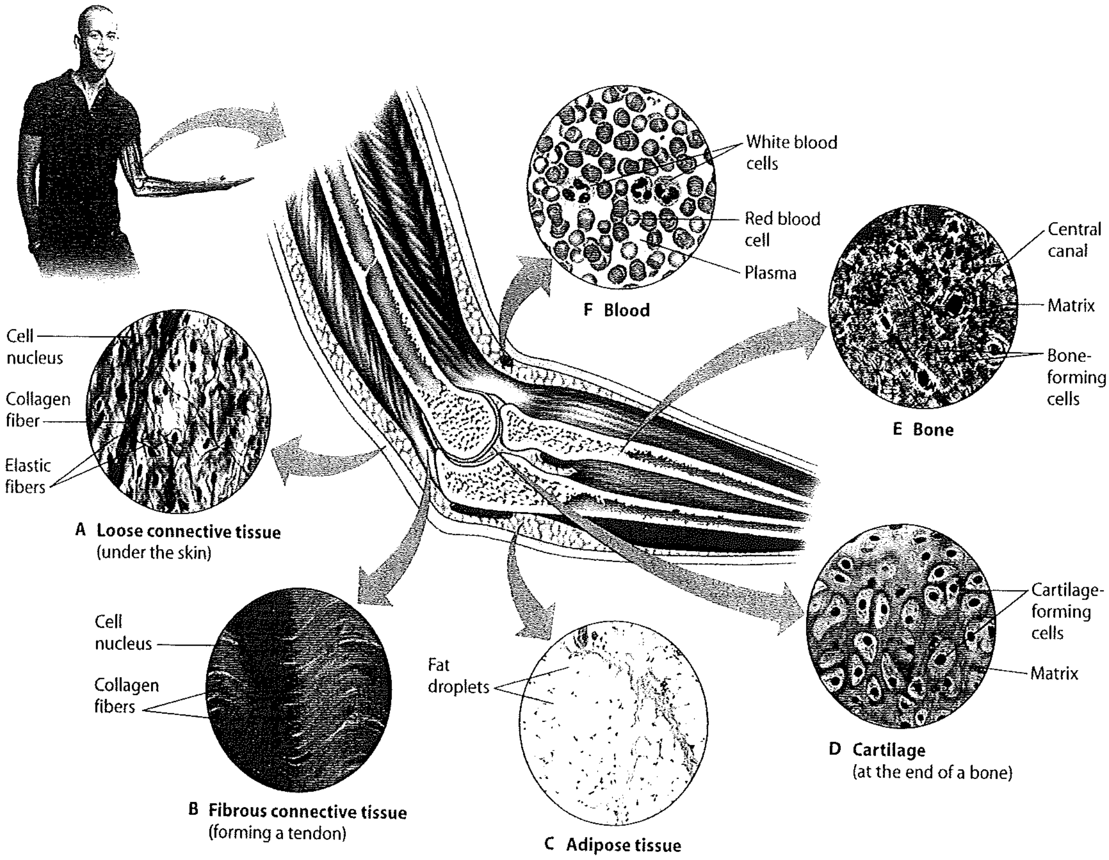
The matrix of **cartilage (Part D)**, a connective tissue that forms a strong but flexible skeletal material, consists of collagen fibers embedded in a rubbery material. Cartilage commonly surrounds the ends of bones, providing a shock-absorbing surface. It also supports your ears and nose and forms the cushioning disks between your vertebrae.

Bone (Part E) has a matrix of collagen fibers embedded in a hard mineral substance made of calcium, magnesium, and phosphate. The combination of fibers and minerals makes bone strong without being brittle. The microscopic structure of compact regions of bones contains repeating circular layers of matrix, each with a central canal containing blood vessels and nerves. Like other tissues, bone contains living cells and can therefore grow as you grow and mend when broken.

Blood (Part F) transports substances throughout your body and thus functions differently from other connective tissues. Its extensive extracellular matrix is a liquid called plasma, which consists of water, salts, and dissolved proteins. Suspended in the plasma are red blood cells, which carry oxygen; white blood cells, which function in defense against disease; and platelets, which aid in blood clotting.

? Why does blood qualify as a type of connective tissue?

Because it consists of a relatively sparse population of cells surrounded by a noncellular matrix, which in this case is a fluid called plasma.



▲ **Figure 10.4** Types of connective tissue

10.5 Muscle tissue functions in movement

Muscle tissue is the most abundant tissue in most animals. It consists of long cells called muscle fibers, each containing many molecules of contractile proteins. **Figure 10.5** shows micrographs of the three types of vertebrate muscle tissue.

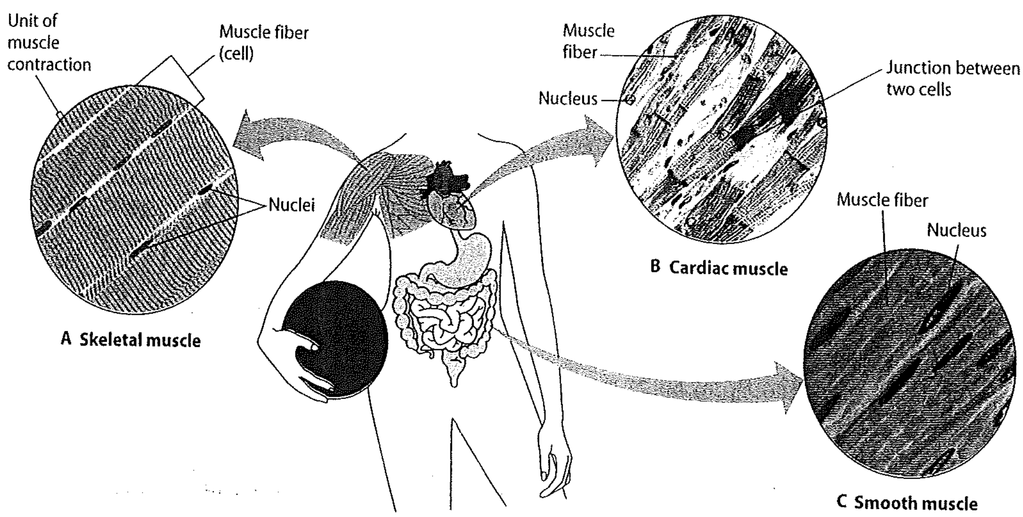
Skeletal muscle (Part A) is attached to your bones by tendons and is responsible for voluntary movements of your body, such as walking or bouncing a ball. The arrangement of the contractile units along the length of muscle fibers gives the cells a striped, or striated, appearance, as you can see in the micrograph below.

Cardiac muscle (Part B) forms the contractile tissue of your heart. It is striated like skeletal muscle, but it is under involuntary control, meaning that you cannot consciously control its contraction. Cardiac muscle fibers are branched, interconnecting at specialized junctions that rapidly relay the signal to contract from cell to cell during your heartbeat.

Smooth muscle (Part C) gets its name from its lack of striations. Smooth muscle is found in the walls of your digestive tract, arteries, and other internal organs. It is responsible for involuntary body activities, such as the movement of food through your intestines. Smooth muscle cells are spindle-shaped and contract more slowly than skeletal muscles, but can sustain contractions for a longer period of time.

? The muscles responsible for a gecko climbing a wall are ________ muscles.

skeletal.



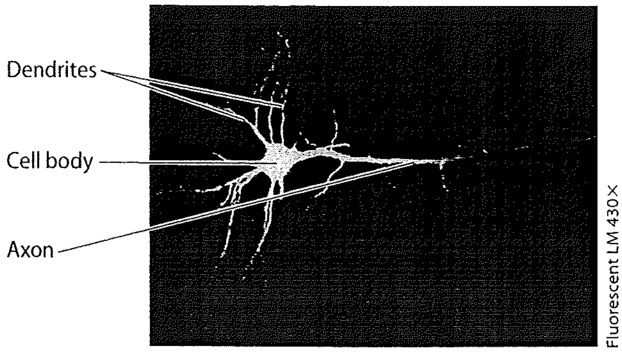
▲ **Figure 10.5** The three types of muscle tissue

10.6 Nervous tissue forms a communication network

Nervous tissue senses stimuli and rapidly transmits information. Nervous tissue is found in your brain and spinal cord, as well as in the nerves that transmit signals throughout your body.

The structural and functional unit of nervous tissue is the nerve cell, or **neuron**, which is uniquely specialized to conduct electrical nerve impulses. As you can see in the micrograph in **Figure 10.6**, a neuron consists of a cell body (containing the cell's nucleus and other organelles) and a number of slender extensions. Dendrites and the cell body receive nerve impulses from other neurons. Axons, which are often bundled together into nerves, transmit signals toward other neurons or to an effector, such as a muscle cell.

Nervous tissue actually contains many more supporting cells than neurons. Some of these cells surround and insulate axons, promoting faster transmission of signals. Others help nourish neurons and regulate the fluid around them.



▲ **Figure 10.6** A neuron

? How does the long length of some axons (such as those that extend from your lower spine to your toes) relate to the function of a neuron?

It allows for the transmission of a nerve signal over a long distance directly to specific muscle cells.

Organs and Organ Systems

10.7 Organs are made up of tissues

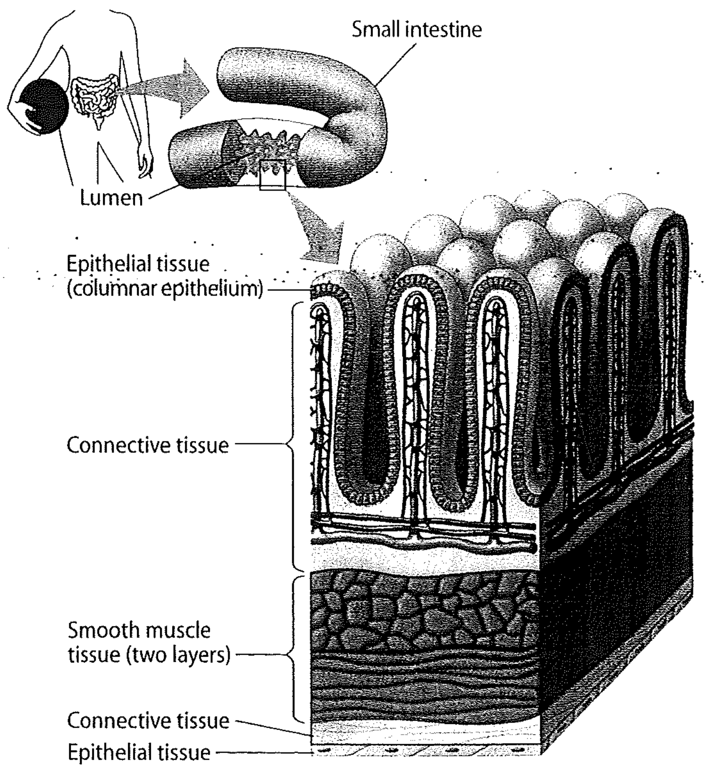
In all but the simplest animals, tissues are arranged into organs that perform specific functions. The heart, for example, while mostly muscle, also has epithelial, connective, and nervous tissues. Epithelial tissue lining the heart chambers prevents leakage and provides a smooth surface over which blood can flow. Connective tissue makes the heart elastic and strengthens its walls. Neurons regulate the contractions of cardiac muscle.

In some organs, tissues are organized in layers, as you can see in the diagram of the small intestine in **Figure 10.7**. The lumen, or interior space, of the small intestine is lined by a columnar epithelium that secretes digestive juices and absorbs nutrients. Notice the finger-like projections that increase the surface area of this lining. Underneath the epithelium (and extending into the projections) is connective tissue, which contains blood vessels. The two layers of smooth muscle, oriented in different directions, propel food through the intestine. The smooth muscle, in turn, is surrounded by another layer of connective tissue and epithelial tissue.

An organ represents a higher level of structure than the tissues composing it, and it performs functions that none of its component tissues can carry out alone. These functions emerge from the coordinated interactions of tissues.

? Explain why a disease that damages connective tissue can impair most of the body's organs.

Connective tissue is a component of most organs.



▲ **Figure 10.7** Tissue layers of the wall of the small intestine

10.8 Organ systems work together to perform life's functions

Just as it takes several different tissues to build an organ, it takes the integration of several organs into organ systems to perform the body's functions. **Figure 10.8** illustrates the organ systems found in humans and other mammals. As you read through the brief descriptions of these systems and study their components in the figure, remember that all of the organ systems are interdependent and work together to create a functional organism.

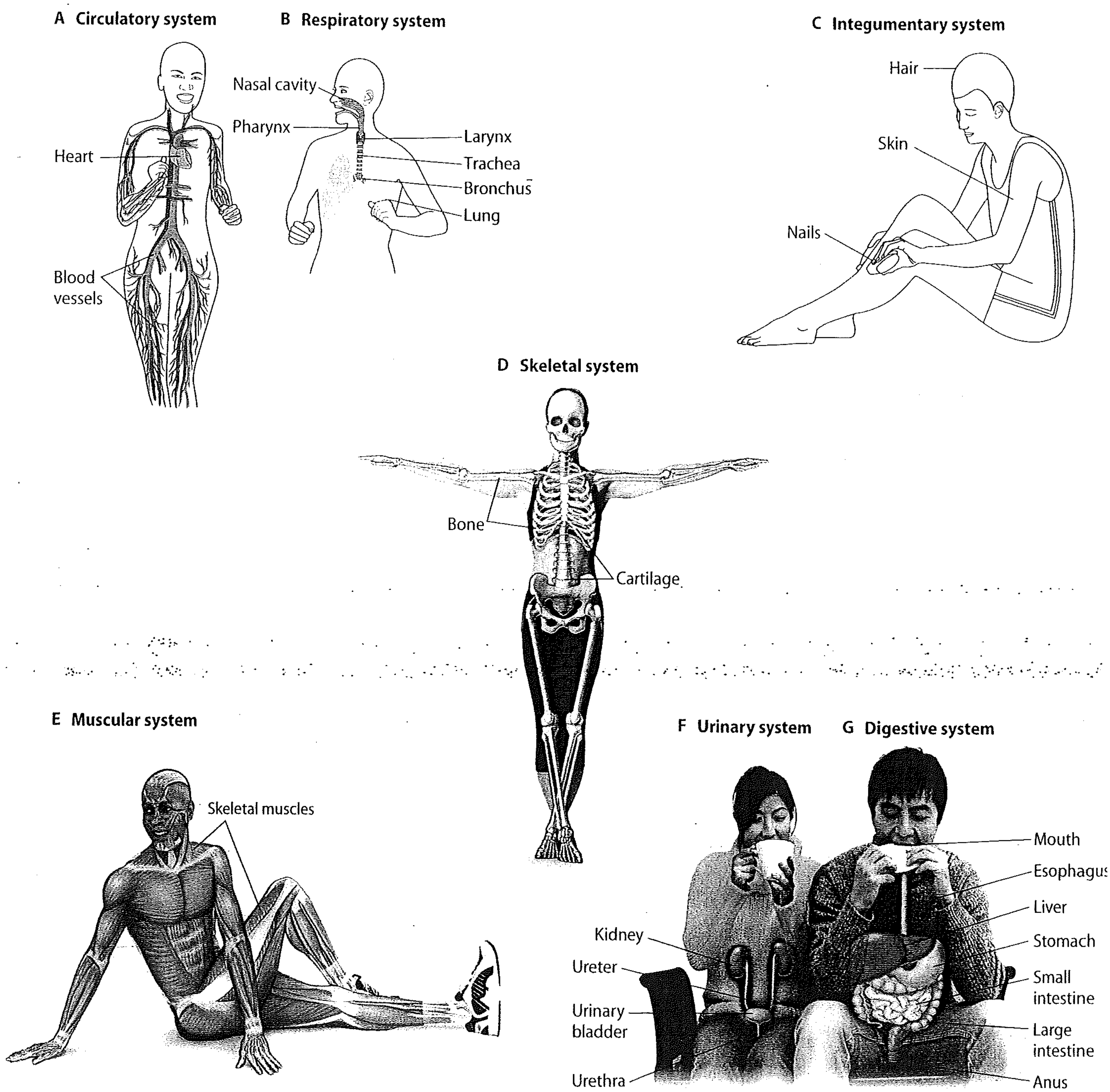
A The **circulatory system** delivers O_2 and nutrients to your body cells and transports CO_2 to the lungs and metabolic wastes to the kidneys.

B The **respiratory system** exchanges gases with the environment, supplying your blood with O_2 and disposing of CO_2.

C The **integumentary system** protects your body against physical injury, infection, excessive heat or cold, and drying out.

D The **skeletal system** supports your body, protects organs such as your brain and lungs, and provides the framework for muscles to produce movement.

E The **muscular system** moves your body, maintains posture, and produces heat.



▲ **Figure 10.8** Human organ systems and their component parts

F The **urinary system** removes waste products from your blood and excretes urine. It also regulates the chemical makeup, pH, and water balance of your blood.

G The **digestive system** ingests and digests your food, absorbs nutrients, and eliminates undigested material.

H The **endocrine system** secretes hormones that regulate the activities of your body, thus maintaining an internal steady state called homeostasis.

I The **lymphatic system** returns excess body fluid to the circulatory system and functions as part of the immune system.

J The **immune system** defends your body against infections and cancer.

K The **nervous system** coordinates your body's activities by detecting stimuli, integrating information, and directing the body's responses.

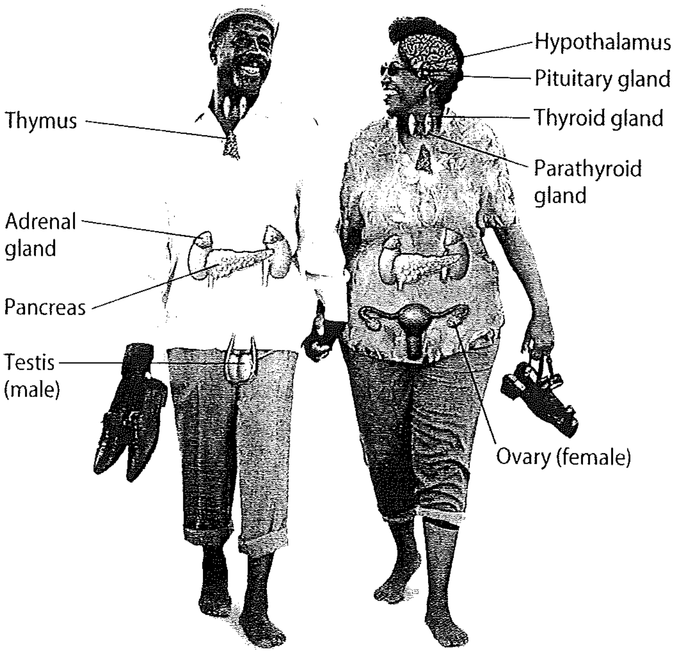
L The **reproductive system** produces gametes and sex hormones. The female system supports a developing embryo and produces milk.

The ability to perform life's functions emerges from the organization and coordination of all the body's organ systems. Indeed, the whole is greater than the sum of its parts.

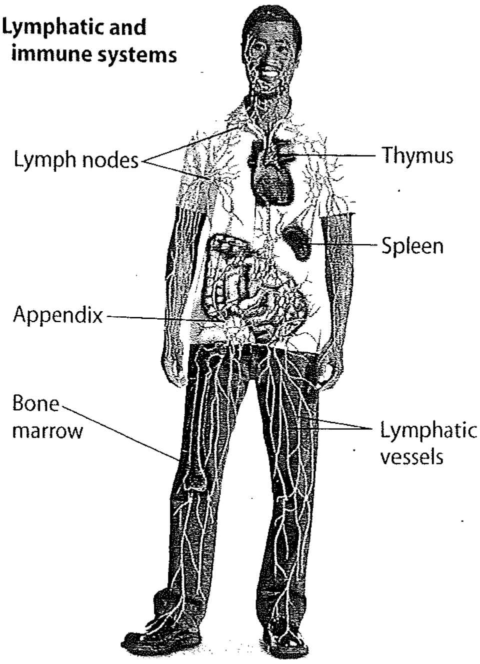
? Which two organ systems are most directly involved in regulating all other systems?

The nervous system and the endocrine system.

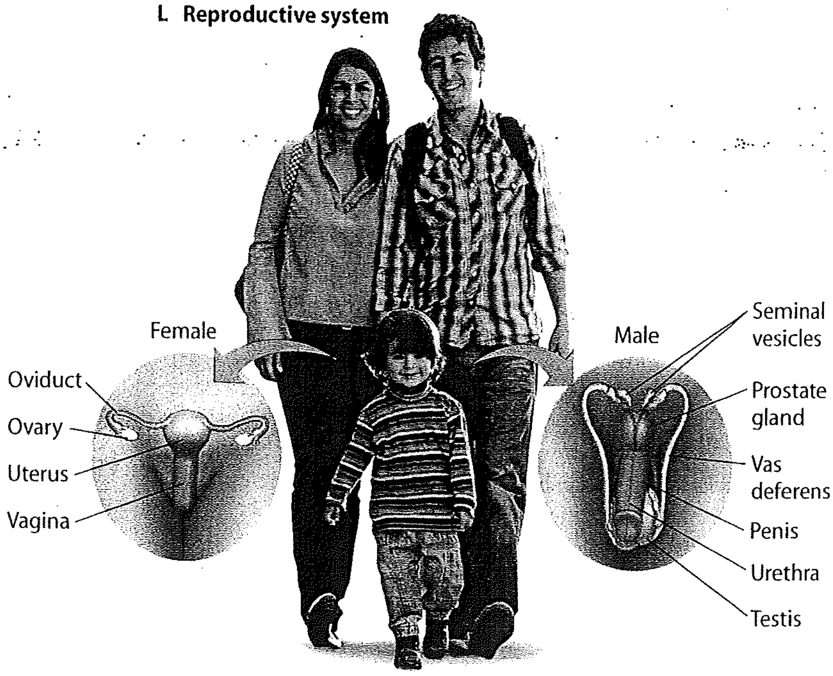
H Endocrine system



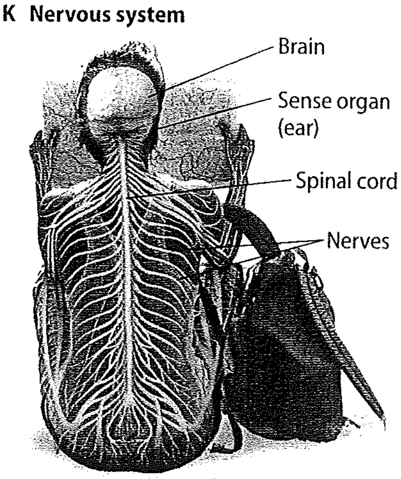
I, J Lymphatic and immune systems



L Reproductive system



K Nervous system



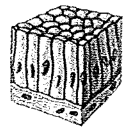
CHAPTER 10 REVIEW

Reviewing the Concepts

Structure and Function in Animal Tissues (10.1–10.6)

10.1 Structure fits function at all levels of organization in the animal body.

10.2 Tissues are groups of cells with a common structure and function.

Function	**10.3 Epithelial tissue covers the body and lines its organs and cavities.**	**10.4 Connective tissue binds and supports other tissues.**	**10.5 Muscle tissue functions in movement.**	**10.6 Nervous tissue forms a communication network.**
Structure	Sheets of closely packed cells	Sparse cells in extra-cellular matrix	Long cells (fibers) with contractile proteins	Neurons with branching extensions; supporting cells
Example	 Columnar epithelium	 Loose connective tissue	 Skeletal muscle	 Neuron

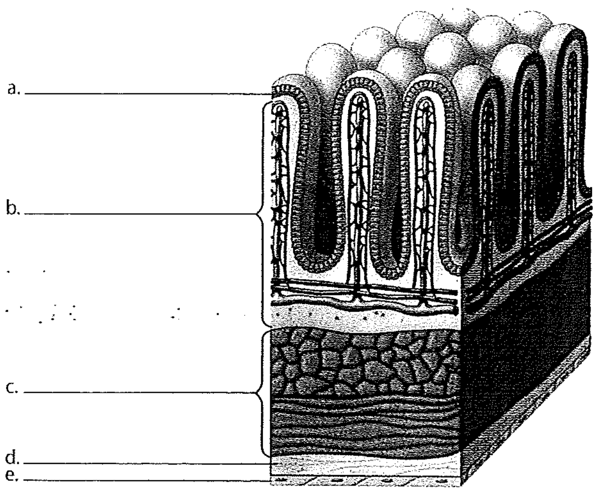
Organs and Organ Systems (10.7–10.8)

10.7 Organs are made up of tissues.

10.8 Organ systems work together to perform life's functions. The integumentary system covers the body. Skeletal and muscular systems support and move it. The digestive and respiratory systems obtain food and oxygen, respectively, and the circulatory system transports these materials. The urinary system disposes of wastes, and the immune and lymphatic systems protect the body from infection. The nervous and endocrine systems control and coordinate body functions. The reproductive system produces offspring.

Connecting the Concepts

1. There are several key concepts introduced in this chapter: Structure correlates with function; an animal's body has a hierarchy of organization with emergent properties at each level; and complex bodies have structural adaptations that increase surface area for exchange. Label the tissue layers shown in this section of the small intestine, and describe how this diagram illustrates these three concepts.



Testing Your Knowledge

Multiple Choice

2. The cells in the human body are in contact with an internal environment consisting of
   a. blood.
   b. connective tissue.
   c. interstitial fluid.
   d. matrix.
   e. mucous membranes.

3. Which of the following body systems facilitates (but doesn't regulate) the functions of the other systems?
   a. respiratory system
   b. endocrine system
   c. digestive system
   d. urinary system
   e. circulatory system

Matching *(Terms in the right-hand column may be used more than once.)*

4. Closely packed cells covering a surface
5. Neurons
6. Adipose tissue, blood, and cartilage
7. May be simple or stratified
8. Scattered cells embedded in matrix
9. Senses stimuli and transmits signals
10. Cells are called fibers
11. Cells may be squamous, cuboidal, or columnar
12. Skeletal, cardiac, or smooth

a. connective tissue
b. muscle tissue
c. nervous tissue
d. epithelial tissue

Describing, Comparing, and Explaining

13. Briefly explain how the structure of each of these tissues is well suited to its function: stratified squamous epithelium in the skin, neurons in the brain, simple squamous epithelium lining the lung, bone in the skull.

14. Describe ways in which the bodies of complex animals are structured for exchanging materials with the environment. Do all animals share such features?

Applying the Concepts

15. Suppose at the end of a hard run on a hot day you find that there are no drinks left in the cooler. If, out of desperation, you dunk your head into the cooler, how might the ice-cold water affect the rate at which your body temperature returns to normal?

Answers to all questions can be found in Appendix 1.

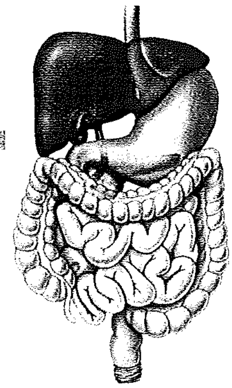
CHAPTER

11 Nutrition and Digestion

BIG IDEAS

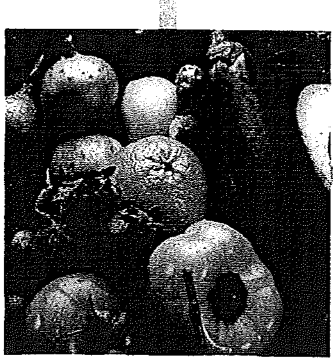
Obtaining and Processing Food
(11.1–11.3)

Animals ingest food, digest it in specialized compartments, absorb nutrients, and eliminate wastes.



The Human Digestive System
(11.4)

Food is processed sequentially in the mouth, stomach, and small intestine, where nutrients are absorbed.



Nutrition
(11.5–11.8)

A healthy diet fuels activities, provides organic building blocks, and provides nutrients a body cannot manufacture.

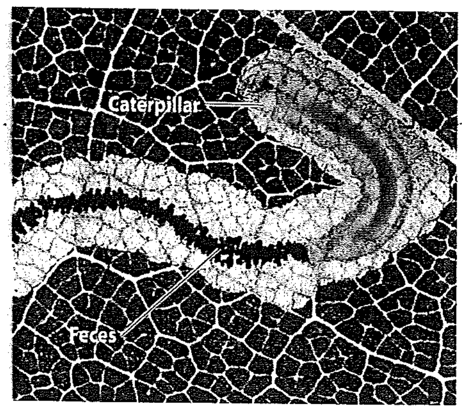
Obtaining and Processing Food

11.1 Animals obtain and ingest their food in a variety of ways

All animals eat other organisms—dead or alive, whole or by the piece. In general, animals fall into one of three dietary categories. **Herbivores**, such as cattle, gorillas, sea urchins, and snails, eat mainly autotrophs—plants and algae. **Carnivores**, such as lions, hawks, spiders, and whales, mostly eat other animals. Animals that consume *both* plants and animals are called **omnivores** (from the Latin *omni*, all, and *vorus*, devouring). Omnivores include humans, as well as crows, cockroaches, and raccoons.

▲ **Figure 11.1A** A suspension feeder: a tube worm filtering food through its tentacles

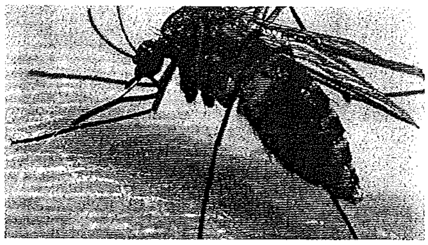
Several types of feeding mechanisms have developed among animals. Many aquatic animals are **suspension feeders**, which sift small organisms or food particles from water. For example, humpback whales use comb-like plates called baleen to strain krill and small fish from the enormous volumes of water they take into their mouths. Clams and oysters are also suspension feeders. A film of mucus on their gills traps tiny morsels suspended in the water, and cilia on the gills sweep the food to the mouth. **Figure 11.1A** shows the feathery tentacles of a suspension-feeding tube worm.



▲ **Figure 11.1B** A substrate feeder: a caterpillar eating its way through the soft tissues inside an oak leaf

Substrate feeders live in or on their food source and eat their way through it. **Figure 11.1B** shows a leaf miner caterpillar, the larva of a moth. The dark spots on the leaf are a trail of feces that the caterpillar leaves in its wake. Other substrate feeders include maggots (fly larvae), which burrow into animal carcasses, and earthworms, which eat their way through soil, digesting partially decayed organic material and helping to aerate and fertilize the soil as they go.

Fluid feeders suck nutrient-rich fluids from a living host. Aphids, for example, tap into the sugary sap in plants. Bloodsuckers, such as mosquitoes and ticks, pierce animals with needlelike mouthparts. The female mosquito in **Figure 11.1C** has just filled her abdomen with a meal of human blood. (Only female mosquitoes suck blood; males live on plant nectar.) In contrast to such parasitic fluid feeders, some fluid feeders actually benefit their hosts. For example, hummingbirds and bees move pollen between flowers as they fluid-feed on nectar.

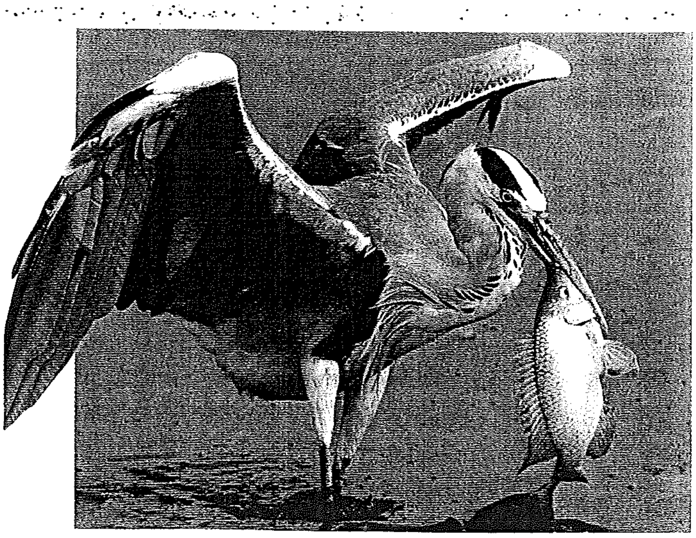


▲ **Figure 11.1C** A fluid feeder: a mosquito sucking blood

Rather than filtering food from water, eating their way through a substrate, or sucking fluids from other animals or plants, most animals are **bulk feeders**, meaning they ingest large pieces of food. **Figure 11.1D** shows a gray heron preparing to swallow its prey whole. A bulk feeder may use such utensils as tentacles, pincers, claws, poisonous fangs, or jaws and teeth to kill its prey or to tear off pieces of meat or vegetation. Whatever the type of food or feeding mechanism, the processing of food involves four stages, as we see next.

? Ring-tailed lemurs eat fruit, leaves, insects, and even small birds. Name their diet category and type of feeding mechanism.

Omnivore and bulk feeder.



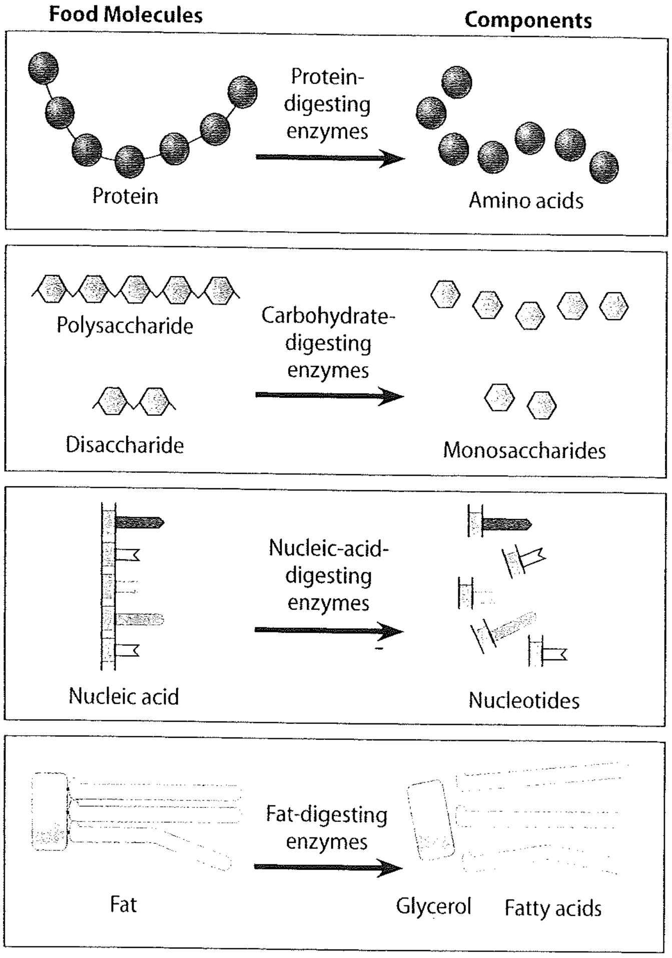
▲ **Figure 11.1D** A bulk feeder: a gray heron preparing to swallow a fish headfirst

11.2 Overview: Food processing occurs in four stages

So far we have discussed what animals eat and how they feed. As shown in **Figure 11.2A**, ① **ingestion**, the act of eating, is only the first of four main stages of food processing. The second stage, ② **digestion**, is the breaking down of food into molecules small enough for the body to absorb. Digestion typically occurs in two phases. First, food may be mechanically broken into smaller pieces. In animals with teeth, the process of chewing or tearing breaks large chunks of food into smaller ones. The second phase of digestion is the chemical breakdown process called hydrolysis. Catalyzed by specific enzymes, hydrolysis breaks the chemical bonds in food molecules by adding water to them (see Module 2.3).

Most of the organic matter in food consists of proteins, fats, and carbohydrates—all large molecules. Animals cannot use these materials directly for two reasons. First, these molecules are too large to pass through plasma membranes into the cells. Second, an animal needs small components to make the molecules of its own body. Most food molecules, for instance, the proteins in the cat's food shown in the figure below, are different from those that make up an animal's body.

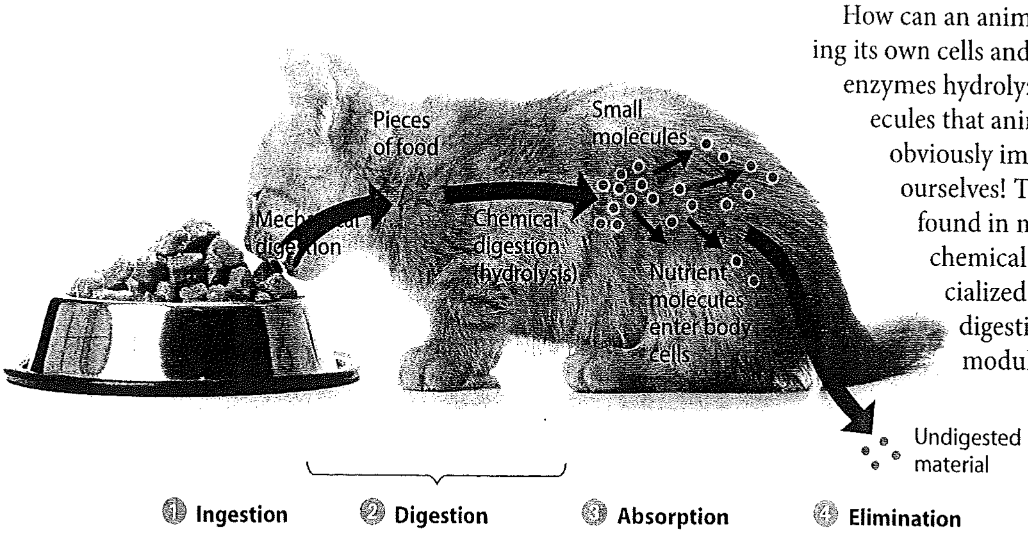
All organisms use the same building blocks to make their macromolecules. For instance, cats, caterpillars, and humans all make their proteins from the same 20 amino acids. Digestion breaks the polymers in food into monomers. As shown in **Figure 11.2B**, proteins are split into amino acids, polysaccharides and disaccharides are broken down into monosaccharides, and nucleic acids are split into nucleotides (and their components). Fats are not polymers, but they are split into their components, glycerol and fatty acids. The animal can then use these small molecules to make the specific large molecules it needs (see Module 5.9).



▲ **Figure 11.2B** Chemical digestion: the breakdown of large organic molecules to their components

In the third stage of food processing, ③ **absorption**, the cells lining the digestive tract take up, or absorb, the products of digestion—small molecules such as amino acids and simple sugars. From the digestive tract, these nutrients travel in the blood to body cells, where they are used to build a cell's large molecules or broken down further to provide energy. In an animal that eats much more than its body immediately uses, many of the nutrient molecules are converted to fat for storage. In the fourth and last stage of food processing, ④ **elimination**, undigested material passes out of the digestive tract.

How can an animal digest food without digesting its own cells and tissues? After all, digestive enzymes hydrolyze the same biological molecules that animals are made of—and it is obviously important to avoid digesting ourselves! The developmental adaptation found in most animal species is the chemical digestion of food within specialized compartments. We discuss digestive compartments in the next module.



▲ **Figure 11.2A** The four main stages of food processing

? **What are the two typical phases of digestion?**

Mechanical breakdown and chemical breakdown (enzymatic hydrolysis).

11.3 Digestion occurs in specialized compartments

The simplest type of digestive compartment is a food vacuole, in which digestion occurs within a cell. After a cell engulfs a food particle, the newly formed food vacuole fuses with a lysosome containing hydrolytic enzymes (see Module 3.9). This type of digestion is common in single-celled protists, but sponges are the only animals that digest their food entirely in food vacuoles. In contrast, most animals have a digestive compartment that is surrounded by, rather than within, body cells. Such compartments enable an animal to devour much larger pieces of food than could fit in a food vacuole.

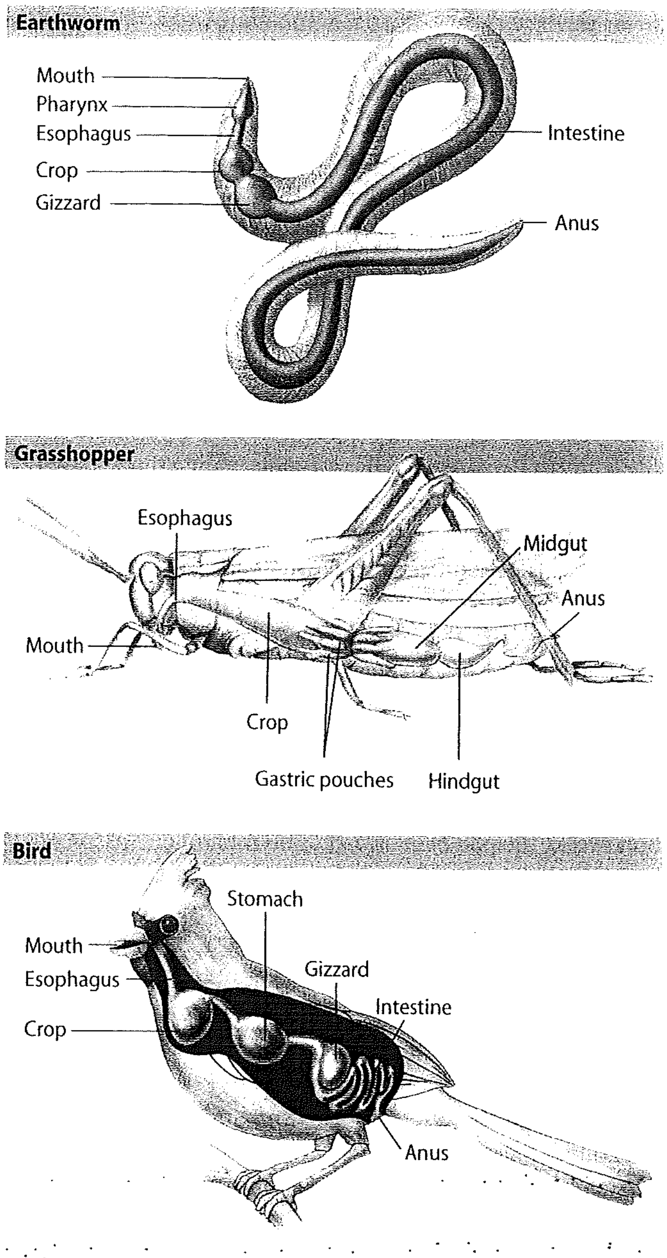
Simpler animals such as cnidarians and flatworms have a **gastrovascular cavity**, a digestive compartment with a single opening, the **mouth**. **Figure 11.3A** shows a hydra digesting a water flea, which it has captured with its tentacles and stuffed into its mouth. ❶ Gland cells lining the gastrovascular cavity secrete digestive enzymes that ❷ break down the food into smaller particles. ❸ Other cells engulf these small food particles, and ❹ digestion is completed in food vacuoles. Undigested material is expelled through the mouth.

Most animals have an **alimentary canal**, a digestive tract with two openings, a mouth and an anus. Because food moves in one direction, specialized regions of the tube can carry out digestion and absorption of nutrients in sequence.

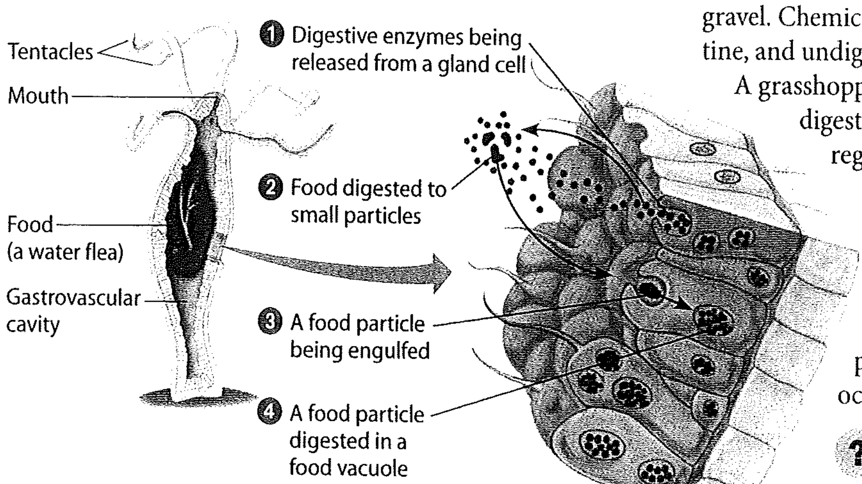
Food entering the mouth usually passes into the **pharynx**, or throat. Depending on the species, the **esophagus** may channel food to a crop, gizzard, or stomach. A **crop** is a pouch-like organ in which food is softened and stored. **Stomachs** and **gizzards** may also store food temporarily, but they are more muscular and they churn and grind the food. Chemical digestion and nutrient absorption occur mainly in the **intestine**. Undigested materials are expelled through the **anus**.

Figure 11.3B illustrates three examples of alimentary canals. The digestive tract of an earthworm includes a muscular pharynx that sucks food in through the mouth. Food passes through the esophagus and is stored in the crop. Mechanical digestion takes place in the muscular gizzard, which pulverizes food with the aid of small bits of sand and gravel. Chemical digestion and absorption occur in the intestine, and undigested material is expelled through the anus.

A grasshopper also has a crop where food is stored. Most digestion in a grasshopper occurs in the midgut region, where projections called gastric pouches function in digestion and absorption. The hindgut mainly reabsorbs water and compacts wastes. Many birds have three separate chambers: a crop, a stomach, and a gravel-filled gizzard, in which food is pulverized. Chemical digestion and absorption occur in the intestine.



▲ **Figure 11.3B** Three examples of alimentary canals.



▲ **Figure 11.3A** Digestion in the gastrovascular cavity of a hydra

? What is an advantage of an alimentary canal, compared to a gastrovascular cavity?

An alimentary canal has specialized regions, which can carry out digestion and absorption sequentially.

The Human Digestive System

11.4 The human digestive system consists of an alimentary canal and accessory glands

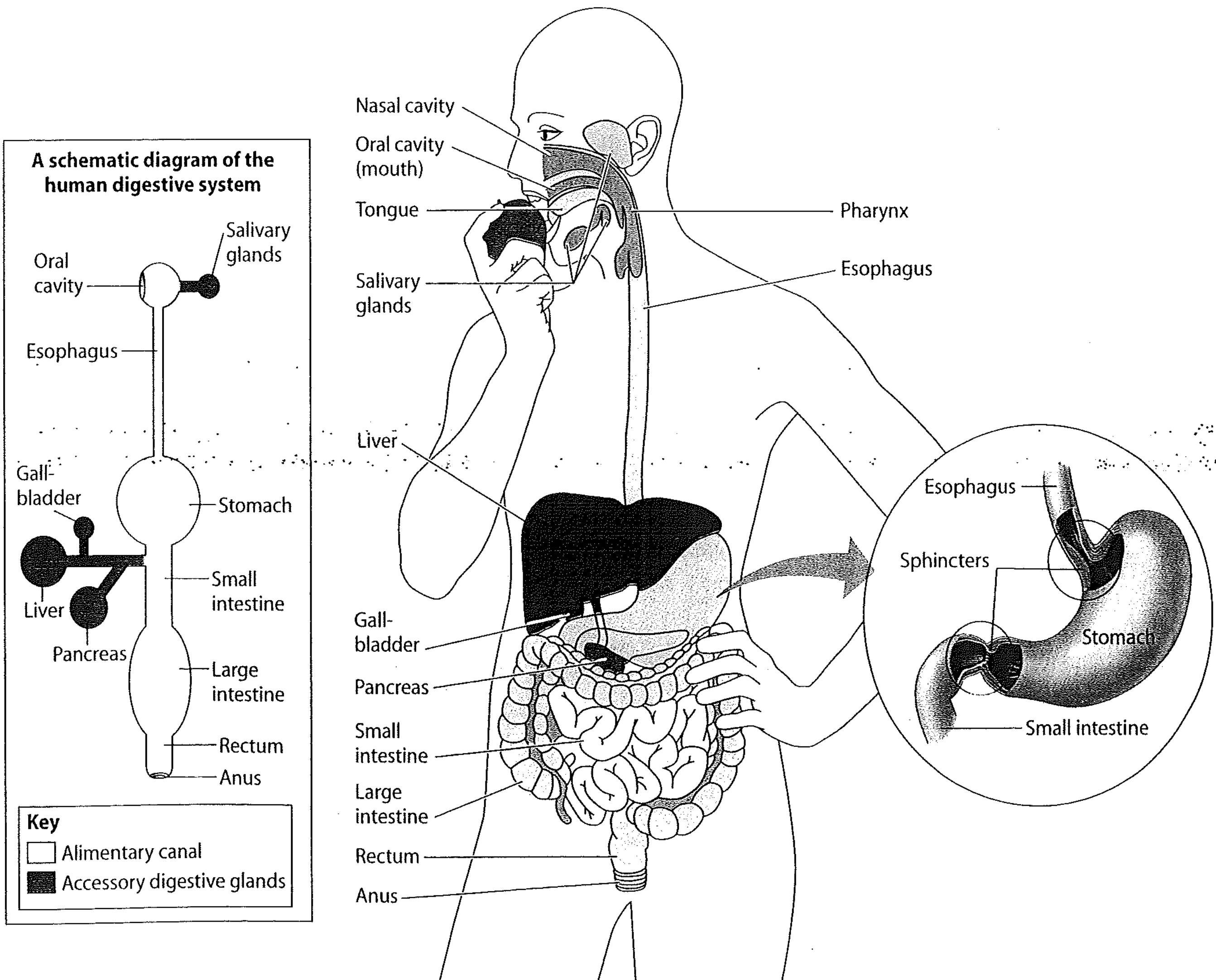
As an introduction to our own digestive system, **Figure 11.4** illustrates the human alimentary canal and its accessory glands. The schematic diagram on the left gives you an overview of the sequence of the organs and the locations of the accessory glands. These glands—the salivary glands, gallbladder, liver, and pancreas—are labeled in blue on the figure. They secrete digestive juices that enter the alimentary canal through ducts.

Food is ingested and chewed in the mouth, or **oral cavity**, and then pushed by the tongue into the pharynx. Once food is swallowed, muscles propel it through the alimentary canal by **peristalsis**, alternating waves of contraction and relaxation of the smooth muscles lining the canal. It is peristalsis that enables you to process and digest food even while lying down. After chewing a bite of food, it only takes 5–10 seconds for it to pass from the pharynx down the esophagus and into your stomach.

As shown in the enlargement, below right, muscular ringlike valves, called **sphincters**, regulate the passage of food into and out of the stomach. The sphincter controlling the passage out of the stomach works like a drawstring to close the stomach off, keeping food there for about 2–6 hours, long enough for stomach acids and enzymes to begin digestion. The final steps of digestion and nutrient absorption occur in the small intestine over a period of 5–6 hours. Undigested material moves slowly through the large intestine (taking 12–24 hours), and feces are stored in the rectum and then expelled through the anus.

? By what process does food move from the pharynx to the stomach of an astronaut in the weightless environment of a space station?

Peristalsis.



▲ **Figure 11.4** The human digestive system

Nutrition

11.5 Overview: An animal's diet must satisfy three needs

All animals—whether herbivores like koalas, carnivores like coyotes, or omnivores like humans—have the same basic nutritional needs. All animals must obtain (1) fuel to power all body activities; (2) organic molecules to build the animal's own molecules; and (3) essential nutrients, substances the animal cannot make for itself.

We have seen that digestion dismantles the large molecules in food. Cells can then use the resulting small molecules for energy or assemble them into their own complex molecules—the proteins, carbohydrates, lipids, and nucleic acids needed to build and maintain cell structure and function.

Eating too little food, too much food, or the wrong mixture of foods can endanger an animal's health. Starting with the need for fuel and paying particular attention to humans, we discuss basic nutritional needs in the rest of this chapter.

? What are the three needs that an adequate diet fills?

Fuel, organic building materials, and essential nutrients.

11.6 Chemical energy powers the body

It takes energy to read this book. It also takes energy to digest your snack, walk to class, and perform all the other activities of your body. Cellular respiration produces the body's energy currency, ATP, by oxidizing organic molecules obtained from food (see Chapter 5). Usually, cells use carbohydrates and fats as fuel sources. Fats are especially rich in energy: The oxidation of a gram of fat liberates more than twice the energy liberated from a gram of carbohydrate or protein. The energy content of food is measured in **kilocalories** (1 kcal = 1,000 calories). The calories listed on food labels or referred to in regard to nutrition are actually kilocalories and are often written as Calories (capital C).

The rate of energy consumption by an animal is called its **metabolic rate**. It is the sum of all the energy used by biochemical reactions over a given time interval. Cellular metabolism must continuously drive several processes for an animal to remain alive. These include cell maintenance, breathing, the beating of the heart, and, in birds and mammals, the maintenance of body temperature. The number of kilocalories a resting animal requires to fuel these essential processes for a given time is called the **basal metabolic rate (BMR)**. The BMR for humans averages 1,300–1,500 kcal per day for adult females and about 1,600–1,800 kcal per day for adult males. This is about equivalent to the rate of energy use by a 75-watt light bulb. But this is only a basal (base) rate—the amount of energy you "burn" lying motionless. Any activity, even working at your desk, consumes kilocalories in addition to the BMR. The more active you are, the greater your actual metabolic rate and the greater the number of kilocalories your body uses per day.

Table 11.6 gives you an idea of the amount of activity it takes for a 68-kg (150-pound) person to use up the kilocalories contained in several common foods. What happens when you take in more Calories than you use? Rather than discarding the extra energy, your cells store it in various forms. Your liver and muscles store energy in the form of glycogen, a polymer of glucose molecules. Most of us store enough glycogen to supply about a day's worth of basal metabolism. Your body also stores excess energy as fat. This happens even if your diet contains little fat because the liver converts excess carbohydrates and proteins to fat. The average human's energy needs can be fueled by the oxidation of only 0.3 kg of fat per day. Most healthy people have enough stored fat to sustain them through several weeks of starvation. Let's consider the essential nutrients that must be supplied in the diet.

? What is the difference between metabolic rate and basal metabolic rate?

Metabolic rate is the total energy used for all activities in a unit of time; BMR is the minimum number of kilocalories that a resting animal needs to maintain life's basic processes for a unit of time.

TABLE 11.6 EXERCISE REQUIRED TO "BURN" THE CALORIES (KCAL) IN COMMON FOODS

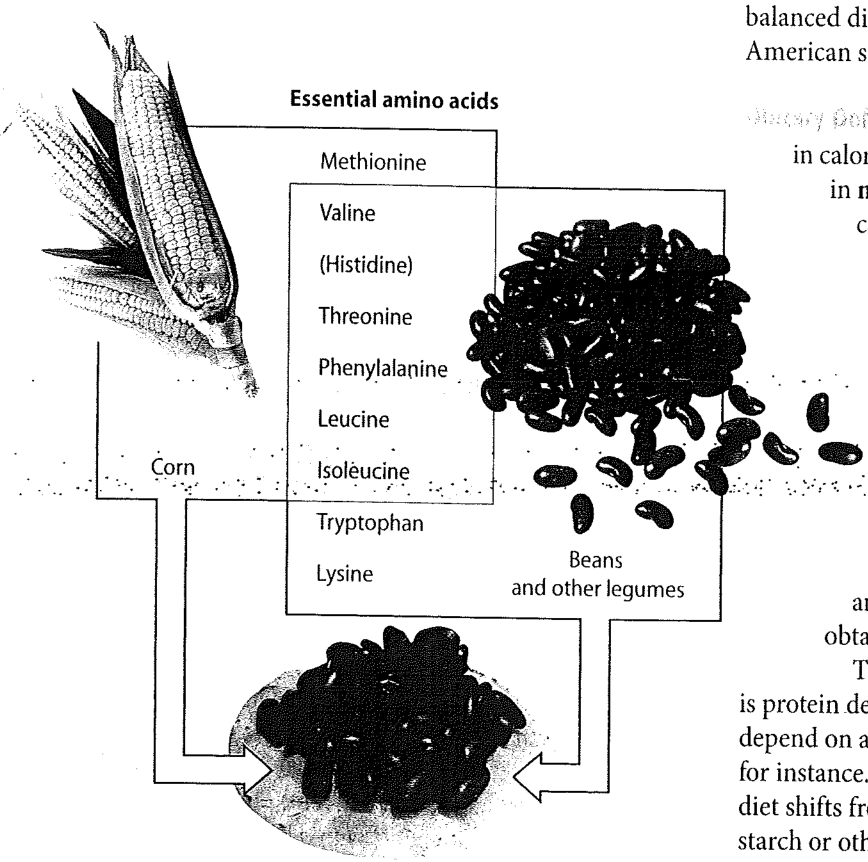
	Jogging	Swimming	Walking
Speed of exercise	**9 min/mi**	**30 min/mi**	**20 min/mi**
kcal "burned" per hour	**775**	**408**	**245**
Cheeseburger (quarter-pound), 417 kcal	32 min	1 hr, 1 min	1 hr, 42 min
Pepperoni pizza (1 large slice), 280 kcal	22 min	42 min	1 hr, 8 min
Non-diet soft drink (12 oz), 152 kcal	12 min	22 min	37 min
Whole wheat bread (1 slice), 65 kcal	5 min	10 min	16 min

These data are for a person weighing 68 kg (150 pounds).

11.7 An animal's diet must supply essential nutrients

Besides providing fuel and organic raw materials, an animal's diet must also supply **essential nutrients**. These are materials that must be obtained in preassembled form because the animal's cells cannot make them from *any* raw material. Some nutrients are essential for all animals, whereas others are needed only by certain species. For example, vitamin C is an essential nutrient for humans and other primates, guinea pigs, and some birds and snakes, but most animals can make vitamin C as needed. There are four classes of essential nutrients: essential fatty acids, essential amino acids, vitamins, and minerals.

Essential Fatty Acids Our cells make fats and other lipids by combining fatty acids with other molecules, such as glycerol (see Module 2.7). We can make most of the fatty acids we need. Those we cannot make, called **essential fatty acids**, must be obtained from our diet. One essential fatty acid, linoleic acid, is especially important because it is needed to make some of the phospholipids of cell membranes. Because seeds, grains, and vegetables generally provide ample amounts of essential fatty acids, deficiencies are rare.



▲ **Figure 11.7** Essential amino acids from a vegetarian diet

Essential Amino Acids Proteins are built from 20 different kinds of amino acids. Adult humans can make 12 of these amino acids from other compounds. The remaining eight, known as the **essential amino acids**, must be obtained from the diet. Infants also require a ninth, histidine. A deficiency of a single essential amino acid impairs protein synthesis and can lead to protein deficiency.

The simplest way to get all the essential amino acids is to eat meat and animal by-products such as eggs, milk, and cheese. The proteins in these products are said to be "complete," meaning they provide all the essential amino acids in the proportions needed by the human body. In contrast, most plant proteins are "incomplete," or deficient in one or more essential amino acids. If you are vegetarian (by choice, or, as for much of the world's population, by economic necessity), the key to good nutrition is to eat a varied diet of plant proteins that together supply sufficient quantities of all the essential amino acids.

Simply by eating a combination of beans and corn, for example, vegetarians can get all the essential amino acids (**Figure 11.7**). The combination of a legume (such as beans, peanuts, or soybeans) and a grain often provides the right balance. Most societies have, by trial and error, developed balanced diets that prevent protein deficiency. The Latin American staple of rice and beans is an example.

Dietary Deficiencies A diet that is chronically deficient in calories or lacks one or more essential nutrients results in **malnutrition**. Failing to obtain adequate nutrition can have serious health consequences.

Living in a country where food is plentiful and most people can afford it, you may find it hard to relate to starvation. But more than 1 billion people in the world do not have enough to eat, and an estimated 4.5 million die of hunger each year, most of them children. Undernutrition, which occurs when diets do not supply sufficient chemical energy, may occur when food supplies are disrupted by drought, wars, or other crises and when severe poverty prevents people from obtaining sufficient food.

The most common type of human malnutrition is protein deficiency resulting from a diet that must depend on a single plant staple—just corn, rice, or potatoes, for instance. Protein deficiency often begins when a child's diet shifts from breast milk alone to food that is mostly starch or other carbohydrates. Such children, if they survive infancy, often have impaired physical and mental development.

Depending on food availability and choices, it is even possible for an overnourished (obese) individual to be malnourished. For example, malnutrition can result from a steady diet of junk food, which offers little nutritional value.

Another cause of undernutrition is anorexia nervosa, an eating disorder in which individuals, most often females, starve themselves compulsively, in response to an intense fear of gaining weight. Bulemia is a pattern of binge eating followed by purging through induced vomiting, abuse of laxatives, or excessive exercise. Both disorders are serious health problems and can even lead to death.

In the next module, we continue our look at essential nutrients—this time vitamins and minerals.

? Look carefully at Figure 11.7. A diet consisting strictly of corn would probably result in a deficiency of which essential amino acids?

Tryptophan and lysine.

11.8 A healthy human diet includes 13 vitamins and many essential minerals

A **vitamin** is an organic nutrient required in your diet, but only in very small amounts. For example, 1 tablespoon of vitamin B_{12} could provide the daily requirement for nearly a million people. Depending on the vitamin, the required daily amount ranges from about 0.01 to 100 mg. To help you imagine how small these amounts are, consider that a small peanut weighs about 1 g, so 100 mg would be one-tenth of a small peanut. And some vitamin requirements are one-ten-thousandth of that!

Table 11.8A lists 13 essential vitamins and their major dietary sources. As you can see from the functions in the body and symptoms of deficiency listed in the table, vitamins are absolutely necessary to your health—helping to keep your skin healthy, your nervous system in good working order, and your vision clear, among dozens of other actions.

Vitamins are classified as water-soluble or fat-soluble. Water-soluble vitamins include the B vitamins and vitamin C. Many B vitamins function in the body as coenzymes, enabling the catalytic functions of enzymes that are used over and over in metabolic reactions. Vitamin C is required in the production of connective tissue.

Fat-soluble vitamins include vitamins A, D, E, and K. Vitamin A is a component of the visual pigments in your eyes. Among populations subsisting on simple rice diets, people are often afflicted with vitamin A deficiency, which can cause blindness or death. Vitamin D aids in calcium absorption and bone formation. Your dietary requirement for vitamin D is variable because you synthesize this vitamin from other molecules when your skin is exposed to sunlight. Vitamin E functions as an antioxidant that helps prevent damage to your cells. Vitamin K is necessary for proper blood clotting.

Minerals are simple inorganic nutrients, also required in small amounts—from less than 1 mg to about 2,500 mg per day. **Table 11.8B**, on the facing page, lists your daily mineral requirements. As you can see from the table, you need the first seven minerals in amounts greater than 200 mg per day (about two-tenths of that small peanut). You need the rest in much smaller quantities. The table includes the dietary sources for each mineral, and lists the functions and the symptoms of deficiency for most of these minerals.

Along with other vertebrates, we humans require relatively large amounts of calcium and phosphorus to construct and maintain our skeleton. Too little calcium, especially before the age of 30, can result in the degenerative bone disease osteoporosis. Calcium is also necessary for the normal functioning of nerves and muscles, and phosphorus is an ingredient of ATP and nucleic acids.

Iron is a component of hemoglobin, the oxygen-carrying protein found in your red blood cells. Vertebrates need iodine to make thyroid hormones, which regulate metabolic rate. Worldwide, iodine deficiency is a serious human health problem and is ranked as the leading cause of preventable mental retardation.

Sodium, potassium, and chlorine are important in nerve function and help maintain the osmotic balance of your cells. Most of us ingest far more salt (sodium chloride) than we need. The average U.S. citizen eats enough salt to provide about 20 times the required amount of sodium. Packaged (prepared) foods and most junk foods contain large amounts of sodium chloride, even if they don't taste very salty. Ingesting too much sodium has been associated with high blood pressure and other health risks.

A varied diet usually includes enough vitamins and minerals and is considered the best source of these nutrients. Such diets meet the **Recommended Dietary Allowances (RDAs)**, minimum amounts of nutrients that are needed each day, as determined by a national scientific panel. The U.S. Department of Agriculture makes specific recommendations for certain population groups, such as additional B_{12} for people over age 50, folic acid for pregnant women, and extra vitamin D for people with dark skin (which blocks the synthesis of this vitamin) and for those exposed to insufficient sunlight.

TABLE 11.8A | VITAMIN REQUIREMENTS OF HUMANS

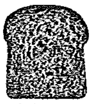
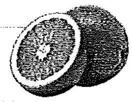
Vitamin	Major Dietary Sources	Functions in the Body	Symptoms of Deficiency
Water-Soluble Vitamins			
Vitamin B_1 (thiamine)	Pork, legumes, peanuts, whole grains 	Coenzyme used in removing CO_2 from organic compounds	Beriberi (tingling, poor coordination, reduced heart function)
Vitamin B_2 (riboflavin)	Dairy products, meats, enriched grains, vegetables	Component of coenzyme FAD	Skin lesions, such as cracks at corners of mouth
Vitamin B_3 (niacin)	Nuts, meats, grains	Component of coenzymes NAD^+ and $NADP^+$	Skin and gastrointestinal lesions, delusions, confusion
Vitamin B_5 (pantothenic acid)	Meats, dairy products, whole grains, fruits, vegetables 	Component of coenzyme A	Fatigue, numbness, tingling of hands and feet
Vitamin B_6 (pyridoxine)	Meats, vegetables, whole grains	Coenzyme used in amino acid metabolism	Irritability, convulsions, muscular twitching, anemia
Vitamin B_7 (biotin)	Legumes, other vegetables, meats	Coenzyme in synthesis of fats, glycogen, and amino acids	Scaly skin inflammation, neuromuscular disorders
Vitamin B_9 (folic acid)	Green vegetables, oranges, nuts, legumes, whole grains	Coenzyme in nucleic acid and amino acid metabolism	Anemia, birth defects
Vitamin B_{12} (cobalamin)	Meats, eggs, dairy products	Production of nucleic acids and red blood cells	Anemia, numbness, loss of balance
Vitamin C (ascorbic acid)	Citrus fruits, broccoli, tomatoes 	Used in collagen synthesis; antioxidant	Scurvy (degeneration of skin, teeth), delayed wound healing
Fat-Soluble Vitamins			
Vitamin A (retinol)	Dark green and orange vegetables and fruits, dairy products 	Component of visual pigments; maintenance of epithelial tissues	Blindness, skin disorders, impaired immunity
Vitamin D	Dairy products, egg yolk	Aids in absorption and use of calcium and phosphorus	Rickets (bone deformities) in children; bone softening in adults
Vitamin E (tocopherol)	Vegetable oils, nuts, seeds 	Antioxidant; helps prevent damage to cell membranes	Nervous system degeneration
Vitamin K	Green vegetables, tea; also made by colon bacteria	Important in blood clotting	Defective blood clotting

TABLE 11.8B | MINERAL REQUIREMENTS OF HUMANS

	Mineral*	Dietary Sources	Functions in the Body	Symptoms of Deficiency
Greater than 200 mg per day required	Calcium (Ca)	Dairy products, dark green vegetables, legumes	Bone and tooth formation, blood clotting, nerve and muscle function	Impaired growth, loss of bone mass
	Phosphorus (P)	Dairy products, meats, grains	Bone and tooth formation, acid-base balance, nucleotide synthesis	Weakness, loss of minerals from bone, calcium loss
	Sulfur (S)	Proteins from many sources	Component of certain amino acids	Impaired growth, fatigue, swelling
	Potassium (K)	Meats, dairy products, many fruits and vegetables, grains	Acid-base balance, water balance, nerve function	Muscular weakness, paralysis, nausea, heart failure
	Chlorine (Cl)	Table salt	Acid-base balance, water balance, nerve function, formation of gastric juice	Muscle cramps, reduced appetite
	Sodium (Na)	Table salt	Acid-base balance, water balance, nerve function	Muscle cramps, reduced appetite
	Magnesium (Mg)	Whole grains, green leafy vegetables	Enzyme cofactor; ATP bioenergetics	Nervous system disturbances
	Iron (Fe)	Meats, eggs, legumes, whole grains, green leafy vegetables	Component of hemoglobin and of electron carriers; enzyme cofactor	Iron-deficiency anemia, weakness, impaired immunity
	Fluorine (F)	Drinking water, tea, seafood	Maintenance of tooth structure	Higher frequency of tooth decay
	Iodine (I)	Seafood, iodized salt	Component of thyroid hormones	Goiter (enlarged thyroid gland)

*Additional minerals required in trace amounts are chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo), selenium (Se), and zinc (Zn). All of these minerals, as well as those in the table, are harmful when consumed in excess.

The subject of vitamin dosage has led to heated scientific and popular debate. Some people argue that RDAs are set too low, and some believe, probably mistakenly, that massive doses of vitamins confer health benefits. In general, any excess water-soluble vitamins consumed will be eliminated in urine. But high doses of niacin have been shown to cause liver damage, and large doses of vitamin C can result in gastrointestinal upset. Excessive amounts of fat-soluble vitamins accumulate in body fat. Thus, overdoses may have toxic effects. Excess vitamin A and K are both linked to liver damage. In addition to the dangers of high salt intake, excessive consumption of all the listed minerals may be harmful. For example, in some regions of Africa where the water supply is especially iron-rich, as much as 10% of the population have liver damage as a result of iron overload.

Nevertheless, when we discuss health concerns relating to vitamins and minerals, most of the time we are concerned with deficiencies. Remember that a diet that doesn't include adequate quantities of fresh fruits and vegetables, either as a result of poor food choices or limited supplies or resources, is unlikely to provide the nutrients needed for good health.

? Which of the vitamins and minerals listed in these tables are involved with the formation or maintenance of bones and teeth?

Vitamin C, vitamin D, calcium, phosphorus, and fluorine.

CHAPTER 11 REVIEW

Reviewing the Concepts

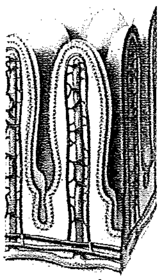
Obtaining and Processing Food (11.1–11.3)

11.1 Animals obtain and ingest their food in a variety of ways. Animals may be herbivores, carnivores, or omnivores and may obtain food by suspension, substrate, fluid, or bulk feeding.

11.2 Overview: Food processing occurs in four stages. The stages are ingestion, digestion, absorption, and elimination.

11.3 Digestion occurs in specialized compartments. Food may be digested in food vacuoles, gastrovascular cavities, or alimentary canals, which run from mouth to anus with specialized regions.

The Human Digestive System (11.4)



11.4 The human digestive system consists of an alimentary canal and accessory glands. The rhythmic muscle contractions of peristalsis squeeze food along the alimentary canal.

Nutrition (11.5–11.8)

11.5 Overview: An animal's diet must satisfy three needs. The diet must provide chemical energy, raw materials for biosynthesis, and essential nutrients.

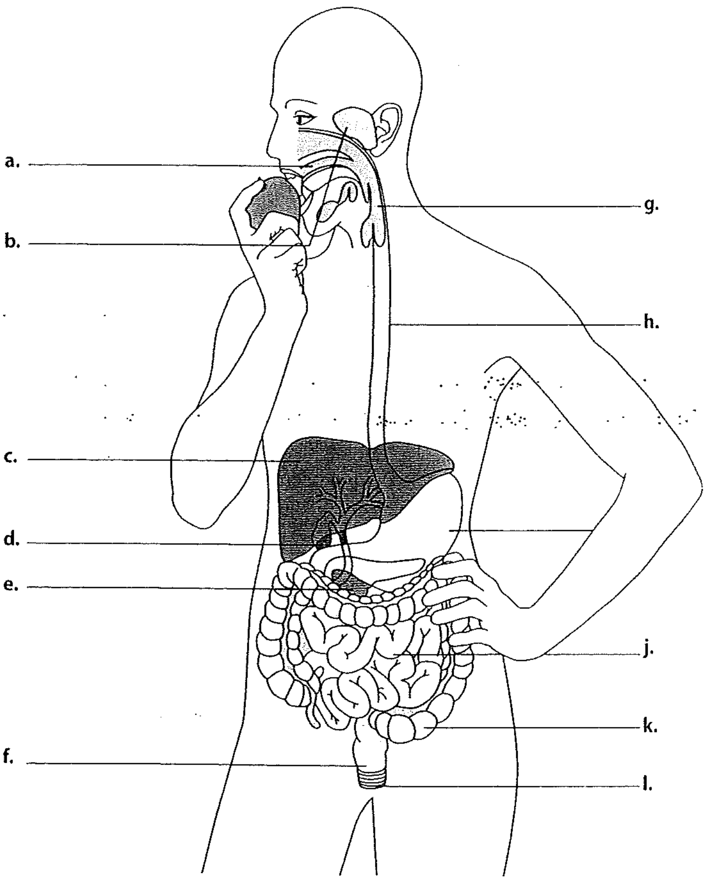
11.6 Chemical energy powers the body. Metabolic rate, the rate of energy consumption, includes the basal metabolic rate (BMR) plus the energy used for other activities.

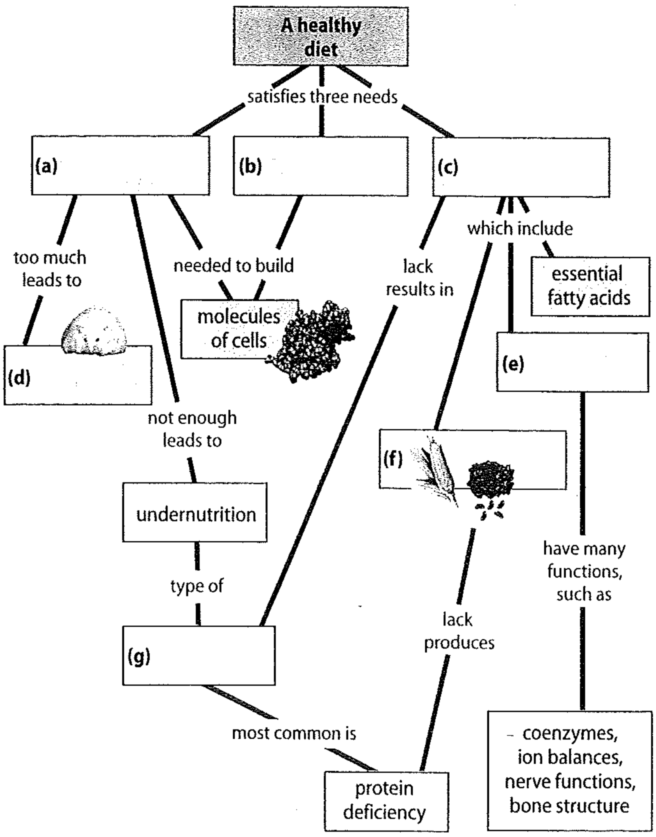
11.7 An animal's diet must supply essential nutrients. Essential fatty acids are easily obtained from the diet. The eight essential amino acids can be obtained from animal protein or the proper combination of plant foods. Malnutrition results from a diet lacking in sufficient calories or essential nutrients.

11.8 A healthy human diet includes 13 vitamins and many essential minerals. Most vitamins function as coenzymes. Minerals are inorganic nutrients that play a variety of roles. A varied diet usually meets the RDAs for these nutrients.

Connecting the Concepts

1. Label the parts of the human digestive system below and indicate the functions of these organs and glands.
2. Complete the following map summarizing the nutritional needs of animals that are met by a healthy diet.





Testing Your Knowledge

Multiple Choice

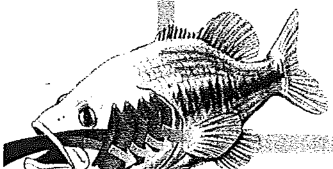
3. Earthworms, which are substrate feeders,
   a. feed mostly on mineral substrates.
   b. filter small organisms from the soil.
   c. are bulk feeders.
   d. are herbivores that eat autotrophs.
   e. eat their way through the soil, feeding on partially decayed organic matter.
4. Which of the following statements is false?
   a. A healthy human has enough stored fat to supply calories for several weeks.
   b. An increase in leptin levels leads to an increase in appetite and weight gain.
   c. The interconversion of glucose and glycogen takes place in the liver.
   d. After glycogen stores are filled, excessive calories are stored as fat, regardless of their original food source.
   e. Carbohydrates and fats are normally used as fuel before proteins are used.
5. Which of the following is mismatched with its function?
   a. most B vitamins—coenzymes
   b. vitamin E—antioxidant
   c. vitamin K—blood clotting
   d. iron—component of thyroid hormones
   e. phosphorus—bone formation, nucleotide synthesis
6. Why is it necessary for healthy vegetarians to combine different plant foods or eat some eggs or milk products?
   a. to make sure they obtain sufficient calories
   b. to provide sufficient vitamins
   c. to make sure they ingest all essential fatty acids
   d. to make their diet more interesting
   e. to provide all essential amino acids for protein synthesis

Answers to all questions can be found in Appendix 1.

CHAPTER

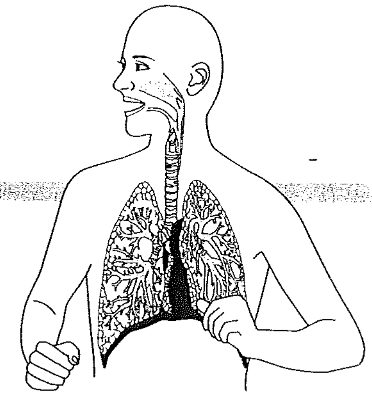
12 Gas Exchange

BIG IDEAS



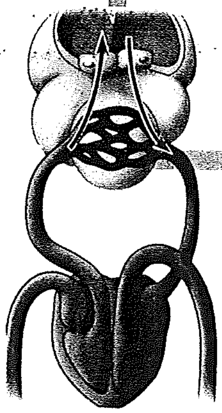
Mechanisms of Gas Exchange
(12.1–12.2)

Gas exchange occurs across thin, moist surfaces in respiratory organs such as gills, tracheal systems, and lungs.



The Human Respiratory System
(12.3)

Air travels through branching tubes to the lungs, where gases are exchanged with the blood.

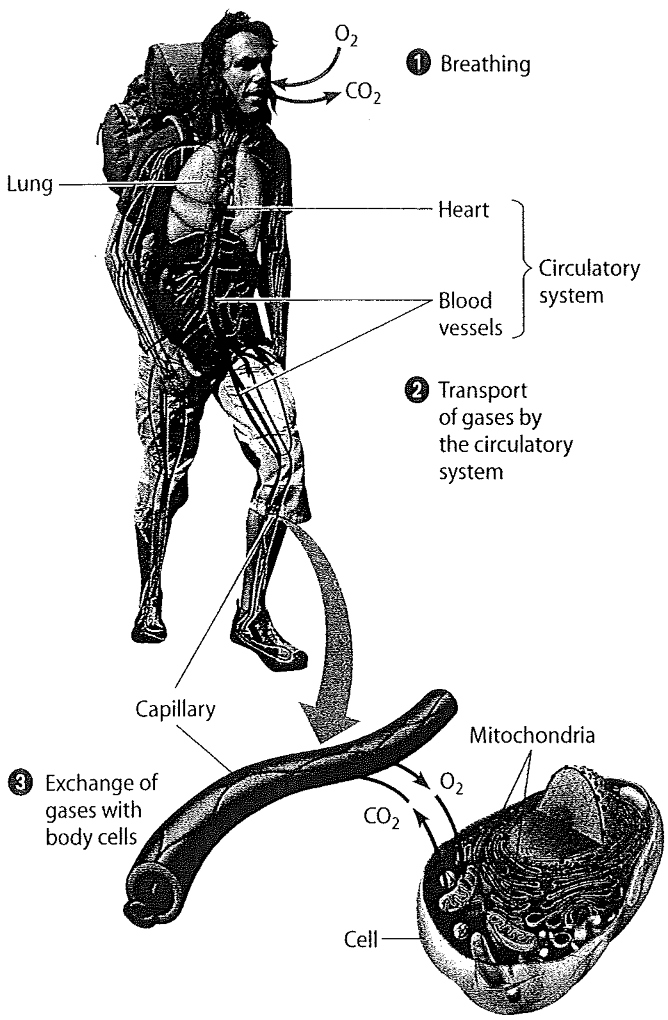


Transport of Gases in the Human Body
(12.4–12.5)

The circulatory system transports O_2 to body tissues and returns CO_2 to the lungs.

Mechanisms of Gas Exchange

12.1 Overview: Gas exchange in humans involves breathing, transport of gases, and exchange with body cells



▲ **Figure 12.1** The three phases of gas exchange in a human

Gas exchange makes it possible for you to put to work the food molecules the digestive system provides. **Figure 12.1** presents an overview of the three phases of gas exchange in humans and other animals with lungs. ❶ Breathing: As you inhale, a large, moist internal surface is exposed to the air entering the lungs. Oxygen (O_2) diffuses across the cells lining the lungs and into surrounding blood vessels. At the same time, carbon dioxide (CO_2) diffuses from the blood into the lungs. As you exhale, CO_2 leaves your body.

❷ Transport of gases by the circulatory system: The O_2 that diffused into the blood attaches to hemoglobin in red blood cells. The red vessels in the figure are transporting O_2-rich blood from the lungs to capillaries in the body's tissues. CO_2 is also transported in blood, from the tissues back to the lungs, carried in the blue vessels shown here.

❸ Exchange of gases with body cells: Your cells take up O_2 from the blood and release CO_2 to the blood. As you learned in Chapter 5, O_2 functions in cellular respiration in the mitochondria as the final electron acceptor in the stepwise breakdown of fuel molecules. H_2O and CO_2 are waste products, and ATP is produced that will power cellular work. The gas exchange occurring as we breathe is often called respiration; do not confuse this exchange with cellular respiration.

Cellular respiration requires a continuous supply of O_2 and the disposal of CO_2. Gas exchange involves both the respiratory and circulatory systems in servicing your body's cells.

? Humans cannot survive for more than a few minutes without O_2. Why?

Cells require a steady supply of O_2 for cellular respiration to produce enough ATP to function. Without enough ATP, cells and the organism die.

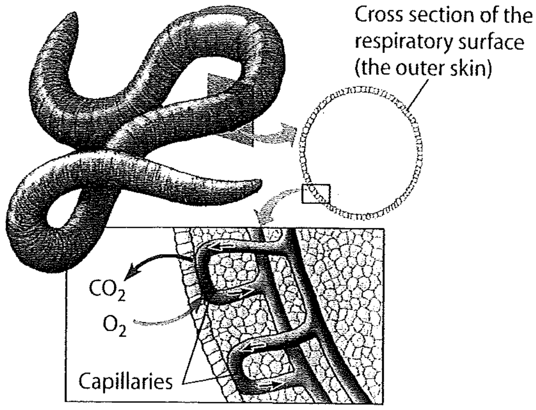
12.2 Animals exchange O_2 and CO_2 across moist body surfaces

The part of an animal's body where gas exchange with the environment occurs is called the respiratory surface. Respiratory surfaces are made up of living cells, and like all cells, their plasma membranes must be wet to function properly. Thus, respiratory surfaces are always moist.

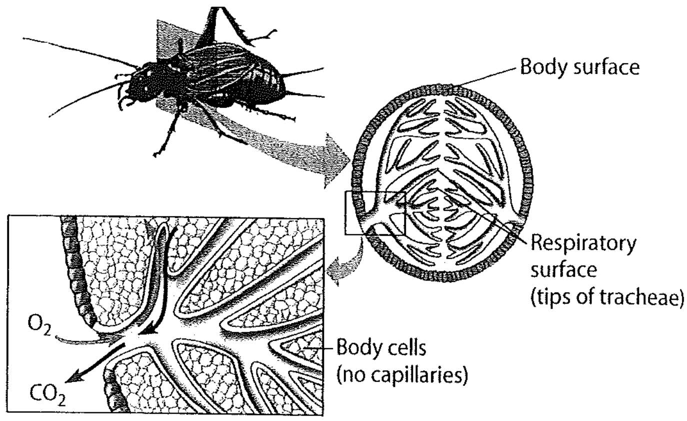
Gas exchange takes place by diffusion. The surface area of the respiratory surface must be large enough to take up sufficient O_2 for every cell in the body. Usually, a single layer of cells forms the respiratory surface. This thin, moist layer allows O_2 to diffuse rapidly into the circulatory system or directly into body tissues and also allows CO_2 to diffuse out.

The four figures on the next page illustrate, in simplified form, four types of respiratory organs, structures in which gas exchange with the external environment occurs. In each of these figures, the circle represents a cross section of the animal's body through the respiratory surface. The yellow areas represent the respiratory surfaces; the green outer circles represent body surfaces with little or no role in gas exchange. The boxed enlargements show gas exchange occurring across the respiratory surface.

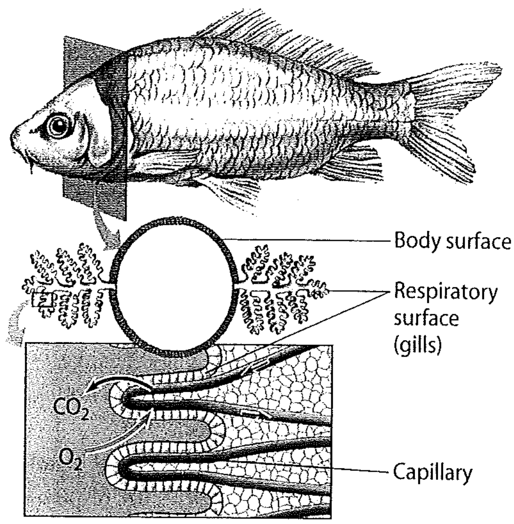
Some animals use their entire outer skin as a gas exchange organ. The earthworm in **Figure 12.2A** is an example. The cross-sectional diagram shows its whole body surface as yellow; there are no specialized gas exchange surfaces. Oxygen diffuses into a dense network of thin-walled capillaries lying just beneath the skin. Earthworms and other skin-breathers must live in damp places or in water because their whole body surface has to stay moist. Animals that breathe only through



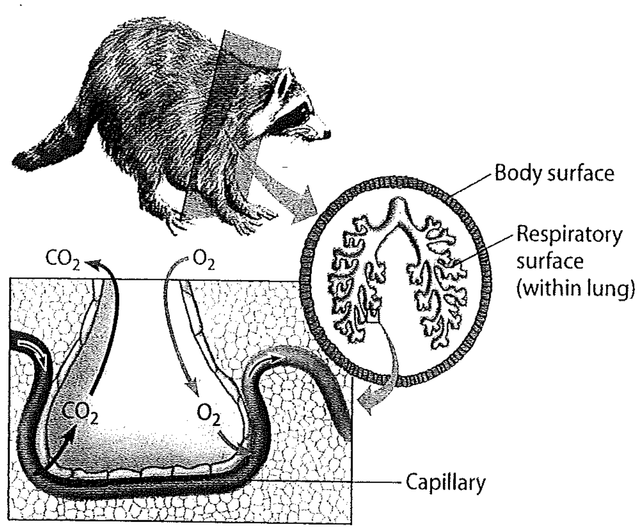
▲ **Figure 12.2A** The skin: the outer body surface



▲ **Figure 12.2C** A tracheal system: air tubes that extend throughout the body



▲ **Figure 12.2B** Gills: extensions of the body surface



▲ **Figure 12.2D** Lungs: internal thin-walled sacs

their skin are generally small, and many are long and thin or flattened. These shapes provide a high ratio of respiratory surface to body volume, allowing for sufficient gas exchange for all the cells in the body.

In most animals, the skin surface is not extensive enough to exchange gases for the whole body. Consequently, certain parts of the body have become adapted as highly branched respiratory surfaces with large surface areas. Such gas exchange organs include gills, tracheal systems, and lungs.

Gills have developed in most aquatic animals. **Gills** are extensions, or outfoldings, of the body surface specialized for gas exchange. Many marine worms have flap-like gills that extend from each body segment. The gills of clams and crayfish are clustered in one body location. A fish **(Figure 12.2B)** has a set of feather-like gills on each side of its head. As indicated in the enlargement, gases diffuse across the gill surface between the water and the blood. Because the respiratory surfaces of aquatic animals extend into the surrounding water, keeping the surface moist is not a problem.

In most terrestrial animals, the respiratory surface is folded into the body rather than projecting from it. The infolded surface opens to the air only through narrow tubes, an arrangement that helps retain the moisture that is essential for the cells of the respiratory surfaces to function.

The **tracheal system** of insects **(Figure 12.2C)** is an extensive system of branching internal tubes called tracheae, with a moist, thin epithelium forming the respiratory surface at their tips. The smallest branches exchange gases directly with body cells. Thus, gas exchange in insects requires no assistance from the circulatory system.

Most terrestrial vertebrates have **lungs (Figure 12.2D)**, which are internal sacs lined with moist epithelium. As the diagram indicates, the inner surfaces of the lungs are extensively subdivided, forming a large respiratory surface. Gases are carried between the lungs and the body cells by the circulatory system.

? How does the structure of the respiratory surface of a gill or lung fit its function?

These respiratory surfaces are moist and thin so that gases can easily diffuse across them and into or out of the closely associated capillaries. They are highly branched, providing a large surface area for exchange.

The Human Respiratory System

12.3 In mammals, branching tubes convey air to lungs located in the chest cavity

As in all mammals, your lungs are located in your chest, or thoracic cavity, and are protected by the supportive rib cage. The thoracic cavity is separated from the abdominal cavity by a sheet of muscle called the **diaphragm**.

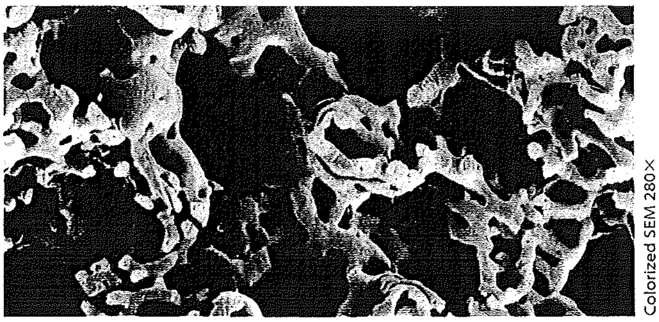
Figure 12.3A shows the human respiratory system (along with the esophagus and heart, for orientation). Air enters your respiratory system through the nostrils. It is filtered by hairs and warmed, humidified, and sampled for odors as it flows through a maze of spaces in the nasal cavity. You can also draw in air through your mouth, but mouth breathing does not allow the air to be processed by your nasal cavity.

From the nasal cavity or mouth, air passes to the **pharynx**, where the paths for air and food cross. As you will remember from the previous chapter, when you swallow food, the **larynx** (the upper part of the respiratory tract) moves upward and tips the epiglottis over the opening of your **trachea**, or windpipe (see Figure 11.6A). The rest of the time, the air passage in the pharynx is open for breathing.

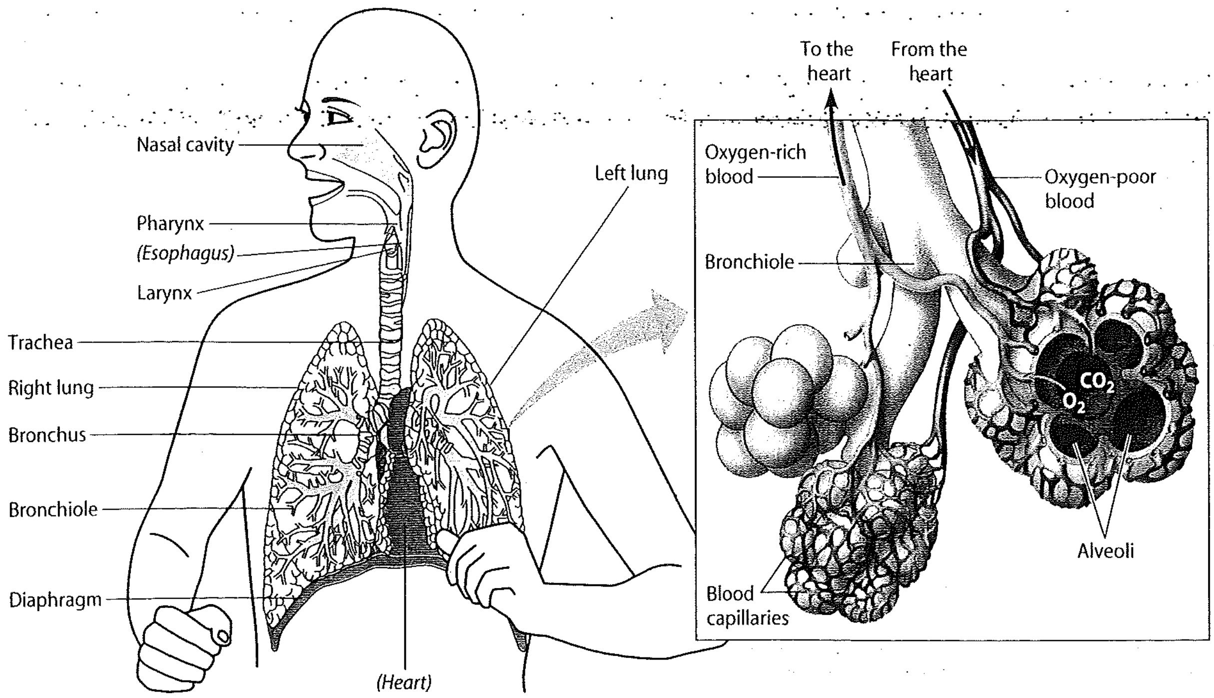
The larynx is often called the voice box. When you exhale, the outgoing air rushes by a pair of **vocal cords** in the larynx, and you can produce sounds by voluntarily tensing muscles that stretch the cords so they vibrate. You produce high-pitched sounds when your vocal cords are tightly stretched and vibrating very fast. When the cords are less tense, they vibrate slowly and produce low-pitched sounds.

From the larynx, air passes into your trachea. Rings of cartilage (shown in the figure in blue) reinforce the walls of the larynx and trachea, keeping this part of the airway open. The trachea forks into two **bronchi** (singular, *bronchus*), one leading to each lung. Within the lung, the bronchus branches repeatedly into finer and finer tubes called **bronchioles**. Bronchitis is a condition in which these small tubes become inflamed and constricted, making breathing difficult.

As the enlargement on the right of Figure 12.3A shows, the bronchioles dead-end in grapelike clusters of air sacs called **alveoli** (singular, *alveolus*). Each of your lungs contains millions of these tiny sacs. Together they have a surface area of about 100 m^2, 50 times that of your skin. The inner surface of each alveolus is lined with a thin layer of epithelial cells. The O_2 in inhaled air dissolves in a film of moisture on the epithelial cells. It then diffuses across the epithelium and into the dense web of blood capillaries that surrounds each alveolus. **Figure 12.3B** is a scanning electron micrograph showing the network of capillaries enclosing the alveoli. (The alveoli in this micrograph appear as empty spaces because the blood vessels were injected with a solution that hardened to form casts of the capillaries, and the tissues of the alveoli were then dissolved.) This close association between capillaries and alveoli also enables CO_2 to diffuse the opposite way—from the capillaries, across the epithelium of the alveolus, into the air space, and finally out in the exhaled air.



▲ **Figure 12.3B** A colorized electron micrograph showing the network of capillaries that surround the alveoli in the lung



▲ **Figure 12.3A** The anatomy of the human respiratory system (left) and details of the alveoli (right)

The major branches of your respiratory system are lined by a moist epithelium covered by cilia and a thin film of mucus. The cilia and mucus are the respiratory system's cleaning system. The beating cilia move mucus with trapped dust, pollen, and other contaminants upward to the pharynx, where it is usually swallowed.

Respiratory Problems Alveoli are so small that specialized secretions called **surfactants** are required to keep them from sticking shut from the surface tension of their moist surface. Respiratory distress syndrome due to a lack of lung surfactant is a common disease seen in babies born 6 weeks or more before their due dates. Surfactants typically appear in the lungs after 33 weeks of embryonic development; birth normally occurs at 38 weeks. Artificial surfactants are now administered through a breathing tube to treat such preterm infants.

Alveoli are highly susceptible to airborne contaminants. Defensive white blood cells patrol them and engulf foreign particles. However, if too much particulate matter reaches the alveoli, the delicate lining of these small sacs becomes damaged and the efficiency of gas exchange drops. Studies have shown a significant association between exposure to fine particles and premature death. Air pollution and tobacco smoke are two sources of these lung-damaging particles.

Exposure to such pollutants can cause continual irritation and inflammation of the lungs and lead to chronic obstructive pulmonary disease (COPD). COPD includes two main conditions: emphysema and chronic bronchitis. In emphysema, the delicate walls of alveoli become permanently damaged and the lungs lose the elasticity that helps expel air during exhalation. With COPD, both lung ventilation and gas exchange are severely impaired. Patients experience labored breathing, coughing, and frequent lung infections. COPD is a major cause of disability and death in the United States.

? How does the structure of alveoli match their function?

Alveoli have a thin, moist epithelium across which dissolved O_2 and CO_2 can easily diffuse into or out of the surrounding capillaries. The huge collective surface area of all the alveoli enables the passage of many gas molecules.

Transport of Gases in the Human Body

12.4 Blood transports respiratory gases

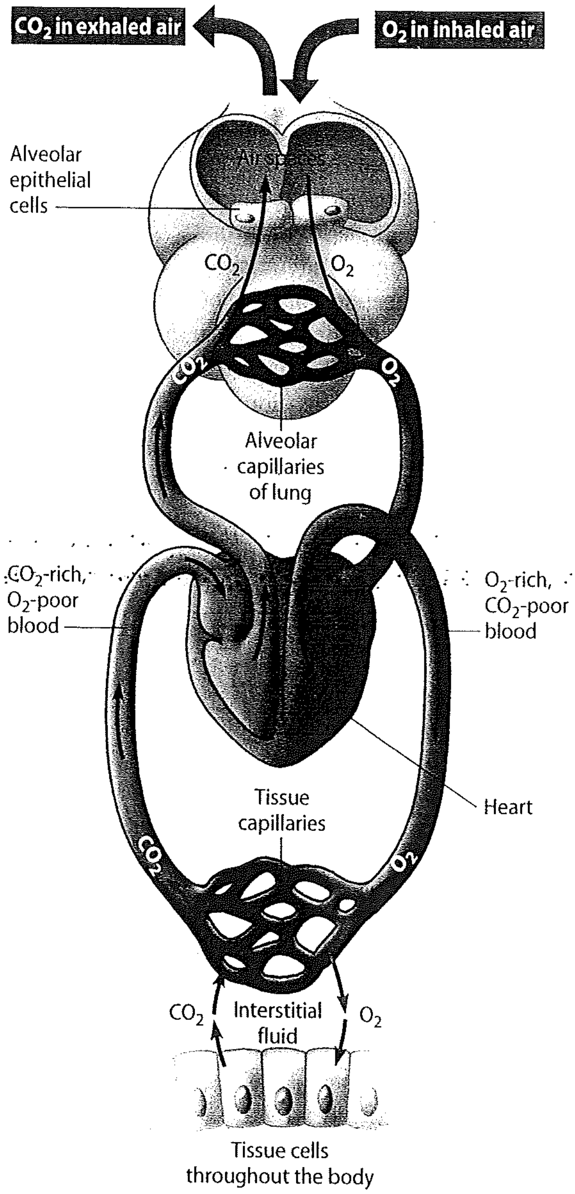
How does oxygen get from your lungs to all the other tissues in your body, and how does carbon dioxide travel from the tissues to your lungs? To answer these questions, we must jump ahead a bit to the subject of Chapter 13 and look at the basic organization of the human circulatory system.

Figure 12.4 is a diagram showing the main components of your circulatory system and their roles in gas exchange. Let's start with the heart, in the middle of the diagram. One side of the heart handles oxygen-poor blood (colored blue). The other side handles oxygen-rich blood (red). As indicated in the lower left of the diagram, oxygen-poor blood returns to the heart from capillaries in body tissues. The heart pumps this blood to the alveolar capillaries in the lungs. Gases are exchanged between air in the alveoli and blood in the capillaries (top of diagram). Blood that has lost CO_2 and gained O_2 returns to the heart and is then pumped out to body tissues.

The exchange of gases between capillaries and the cells around them occurs by the diffusion of gases down gradients of pressure. A mixture of gases, such as air, exerts pressure. You see evidence of gas pressure whenever you open a can of soda, releasing the pressure of the CO_2 it contains. Each kind of gas in a mixture accounts for a portion of the total pressure of the mixture. Thus, each gas has what is called a **partial pressure**. Molecules of each kind of gas will diffuse down a gradient of their own partial pressure independently of the other gases. At the bottom of the figure, for instance, O_2 moves from oxygen-rich blood, through the interstitial fluid, and into tissue cells because it diffuses from a region of higher partial pressure to a region of lower partial pressure. The tissue cells maintain this gradient as they consume O_2 in cellular respiration. The CO_2 produced as a waste product of cellular respiration diffuses down its own partial pressure gradient out of tissue cells and into the capillaries. Diffusion down partial pressure gradients also accounts for gas exchange in the alveoli.

? What is the physical process underlying gas exchange?

Diffusion of each gas down its partial pressure gradient.

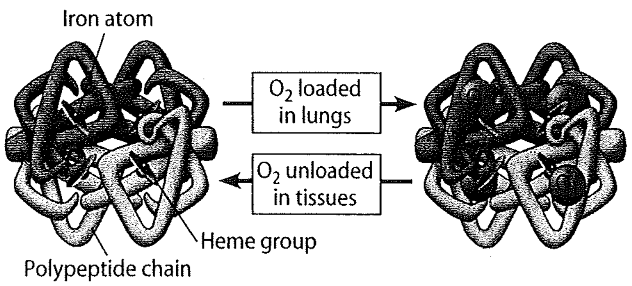


▲ **Figure 12.4** Gas transport and exchange in the body

12.5 Hemoglobin carries O_2, helps transport CO_2, and buffers the blood

Oxygen is not highly soluble in water, and most animals transport O_2 bound to proteins called respiratory pigments. These molecules have distinctive colors, hence the name pigment. Many molluscs and arthropods use a blue, copper-containing pigment. Almost all vertebrates and many invertebrates use **hemoglobin**, an iron-containing pigment that turns red when it binds O_2.

Each of your red blood cells is packed with about 250 million molecules of hemoglobin. A hemoglobin molecule consists of four polypeptide chains of two different types, depicted with two shades of purple in **Figure 12.5**. Attached to each polypeptide is a chemical group called a heme (colored blue in the figure), at the center of which is an iron atom (black). Each iron atom binds one O_2 molecule. Thus, every hemoglobin molecule can carry up to four O_2 molecules. Hemoglobin loads up with O_2 in the lungs and transports it to the body's tissues. There, hemoglobin unloads some or all of its cargo, depending on the O_2 needs of the cells. The partial pressure of O_2 in the tissue reflects how much O_2 the cells are using and determines how much O_2 is unloaded.



▲ **Figure 12.5** Hemoglobin loading and unloading O_2

Hemoglobin is a multipurpose molecule. It also helps transport CO_2 and assists in buffering the blood. Most of the CO_2 that diffuses from tissue cells into a capillary enters red blood cells, where some of it combines with hemoglobin. The rest reacts with water, forming carbonic acid (H_2CO_3), which then breaks apart into a hydrogen ion (H^+) and a bicarbonate ion (HCO_3^-). This reversible reaction is shown below:

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_2O} \rightleftharpoons \underset{\text{Carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Bicarbonate ion}}{HCO_3^-}$$

Hemoglobin binds most of the H^+ produced by this reaction, minimizing the change in blood pH. The bicarbonate ions diffuse into the plasma, where they are carried to the lungs.

As blood flows through capillaries in the lungs, the reaction is reversed. Bicarbonate ions combine with H^+ to form carbonic acid; carbonic acid is converted to CO_2 and water; and CO_2 diffuses from the blood to the alveoli and leaves the body in exhaled air.

? O_2 in the blood is transported bound to ______ within ______ ______ cells, and CO_2 is mainly transported as ______ ions within the plasma.

hemoglobin · · · red blood · · · bicarbonate

CHAPTER 12 REVIEW

Reviewing the Concepts

Mechanisms of Gas Exchange (12.1–12.2)

12.1 Overview: Gas exchange in humans involves breathing, transport of gases, and exchange with body cells. Gas exchange, the interchange of O_2 and CO_2 between an organism and its environment, provides O_2 for cellular respiration and removes its waste product, CO_2.

12.2 Animals exchange O_2 and CO_2 across moist body surfaces. Respiratory surfaces must be thin and moist for diffusion of O_2 and CO_2 to occur. Some animals use their entire skin as a gas exchange organ. In most animals, gills, a tracheal system, or lungs provide large respiratory surfaces for gas exchange.

The Human Respiratory System (12.3)

12.3 In mammals, branching tubes convey air to lungs located in the chest cavity. Inhaled air passes through the pharynx and larynx into the trachea, bronchi, and bronchioles to the alveoli. Mucus and cilia in the respiratory passages protect the lungs.

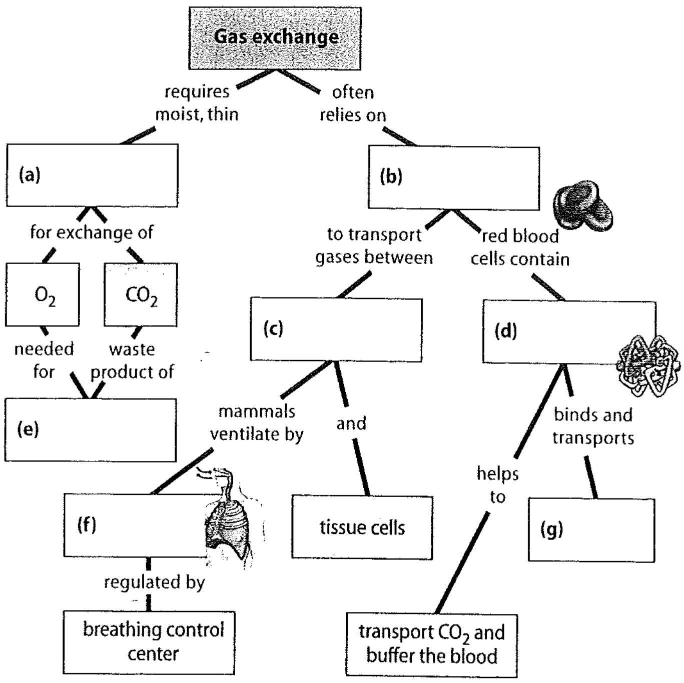
Transport of Gases in the Human Body (12.4–12.5)

12.4 Blood transports respiratory gases. The heart pumps oxygen-poor blood to the lungs, where it picks up O_2 and drops off CO_2. Oxygen-rich blood returns to the heart and is pumped to body cells, where it drops off O_2 and picks up CO_2.

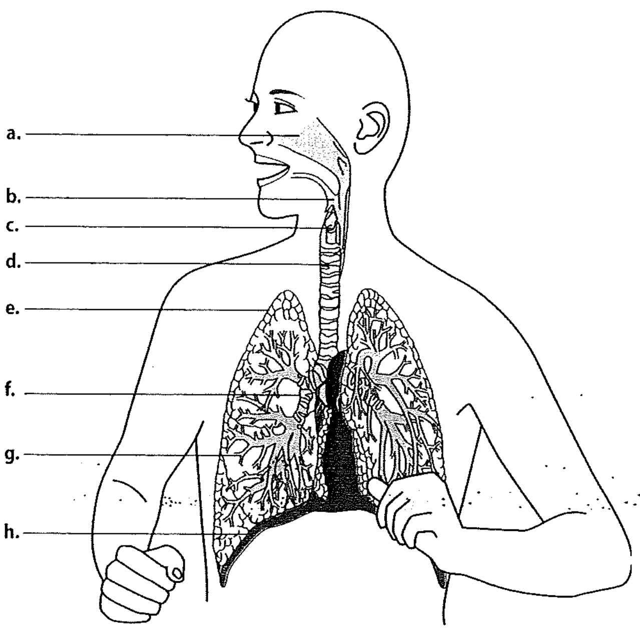
12.5 Hemoglobin carries O_2, helps transport CO_2, and buffers the blood.

Connecting the Concepts

1. Complete the following concept map to review some of the concepts of gas exchange.



2. Label the parts of the human respiratory system.



Testing Your Knowledge

Multiple Choice

3. When you hold your breath, which of the following first leads to the urge to breathe?
   a. falling CO_2
   b. falling O_2
   c. rising CO_2
   d. rising pH of the blood
   e. both c and d

4. Countercurrent gas exchange in the gills of a fish
   a. speeds up the flow of water through the gills.
   b. maintains a gradient that enhances diffusion.
   c. enables the fish to obtain oxygen without swimming.
   d. means that blood and water flow at different rates.
   e. allows O_2 to diffuse against its partial pressure gradient.

5. When you inhale, the diaphragm
   a. relaxes and moves upward.
   b. relaxes and moves downward.
   c. contracts and moves upward.
   d. contracts and moves downward.
   e. is not involved in the breathing movements.

6. In which of the following organisms does oxygen diffuse directly across a respiratory surface to cells, without being carried by the blood?
   a. a grasshopper
   b. a whale
   c. an earthworm
   d. a sparrow
   e. a mouse

7. What is the function of the cilia in the trachea and bronchi?
   a. to sweep air into and out of the lungs
   b. to increase the surface area for gas exchange
   c. to vibrate when air is exhaled to produce sounds
   d. to dislodge food that may have slipped past the epiglottis
   e. to sweep mucus with trapped particles up and out of the respiratory tract

8. What do the alveoli of mammalian lungs, the gill filaments of fish, and the tracheal tubes of insects have in common?
   a. use of a circulatory system to transport gases
   b. respiratory surfaces that are infoldings of the body wall
   c. countercurrent exchange
   d. a large, moist surface area for gas exchange
   e. all of the above

9. Which of the following is the best explanation for why birds can fly over the Himalayas while most humans require oxygen masks to climb these mountains?
   a. Birds are much smaller and require less oxygen.
   b. Birds use positive pressure breathing, whereas humans use negative pressure breathing.
   c. With their one-way flow of air and efficient ventilation, the lungs of birds extract more O_2 from the air.
   d. The circulatory system of birds is much more efficient at delivering oxygen to tissues than is that of humans.
   e. Humans are endotherms and thus require more oxygen than do birds, which are ectotherms.

Describing, Comparing, and Explaining

10. What are two advantages of breathing air, compared with obtaining dissolved oxygen from water? What is a comparative disadvantage of breathing air?

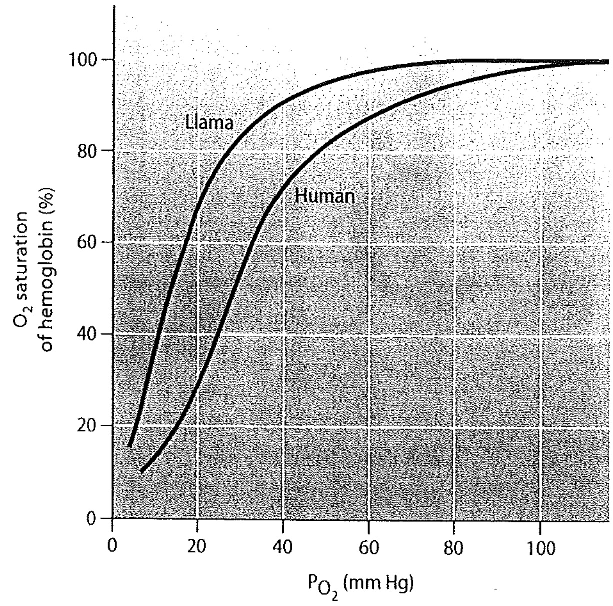
11. Trace the path of an oxygen molecule in its journey from the air to a muscle cell in your arm, naming all the structures involved along the way.

12. Carbon monoxide (CO) is a colorless, odorless gas found in furnace and automobile engine exhaust and cigarette smoke. CO binds to hemoglobin 210 times more tightly than does O_2. (CO binds with an electron transport protein and disrupts cellular respiration.) Explain why CO is such a deadly gas.

Applying the Concepts

13. Partial pressure reflects the relative amount of gas in a mixture and is measured in millimeters of mercury (mm Hg). Llamas are native to the Andes Mountains in South America. The partial pressure of O_2 (abbreviated P_{O_2}) in the atmosphere where llamas live is about half of the P_{O_2} at sea level. As a result, the P_{O_2} in the lungs of llamas is about 50 mm Hg, whereas the P_{O_2} in human lungs at sea level is about 100 mm Hg.

    A dissociation curve for hemoglobin shows the percentage of saturation (the amount of O_2 bound to hemoglobin) at increasing values of P_{O_2}. As you see in the graph opposite, the dissociation curves for llama and human hemoglobin differ. Compare these two curves and explain how the hemoglobin of llamas is an adaptation to living where the air is "thin."



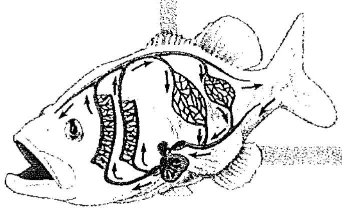
Answers to all questions can be found in Appendix 1.

CHAPTER

13

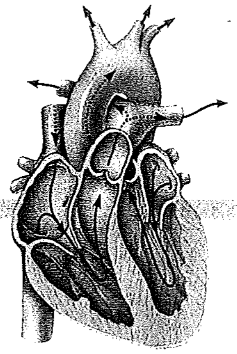
Circulation

BIG IDEAS



Circulatory Systems
(13.1)

Internal transport systems carry materials between exchange surfaces and body cells.



The Human Cardiovascular System and Heart
(13.2–13.3)

The heart pumps blood through the pulmonary circuit and the systemic circuit.

Circulatory Systems

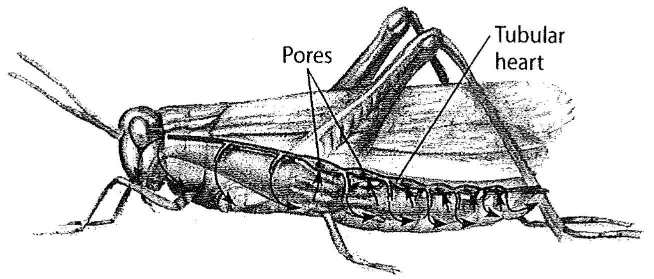
13.1 Circulatory systems facilitate exchange with all body tissues

To sustain life, an animal must acquire nutrients, exchange gases, and dispose of waste products, and these needs ultimately extend to every cell in the body. In most animals, these functions are facilitated by a **circulatory system.** A circulatory system is necessary in any animal whose body is too large or too complex for such exchange to occur by diffusion alone. Diffusion is inadequate for transporting materials over distances greater than a few cell widths—far less than the distance oxygen must travel between your lungs and brain or the distance nutrients must go between your small intestine and the muscles in your arms and legs. An internal transport system must bring resources close enough to cells for diffusion to be effective.

Several types of internal transport have developed in animals. For example, in cnidarians and most flatworms, a central gastrovascular cavity serves both in digestion and in distribution of substances throughout the body. As you saw in Figure 11.3A, the body wall of a hydra is only two or three cells thick, so all the cells can exchange materials directly with the water surrounding the animal or with the fluid in its gastrovascular cavity. Nutrients and other materials have only a short distance to diffuse between cell layers.

A gastrovascular cavity is not adequate for animals with thick, multiple layers of cells. Such animals require a true circulatory system, which consists of a muscular pump **(heart),** a circulatory fluid, and a set of tubes (vessels) to carry the circulatory fluid.

Two basic types of circulatory systems have developed in animals. Many invertebrates, including most molluscs and all arthropods, have an **open circulatory system.** The system is called "open" because fluid is pumped through open-ended vessels and flows out among the tissues; there is no distinction between the circulatory fluid and interstitial fluid. In an insect, such as the grasshopper **(Figure 13.1A)**, pumping of the tubular heart drives body fluid into the head and the rest of the body (black arrows). Body movements help circulate the fluid as materials are exchanged with body cells. When the heart relaxes, fluid enters through several pores. Each pore has a valve that closes when the heart contracts, preventing backflow of the circulating fluid. In insects, respiratory gases are conveyed to and from body cells by the tracheal system (not shown here), not by the circulatory system.



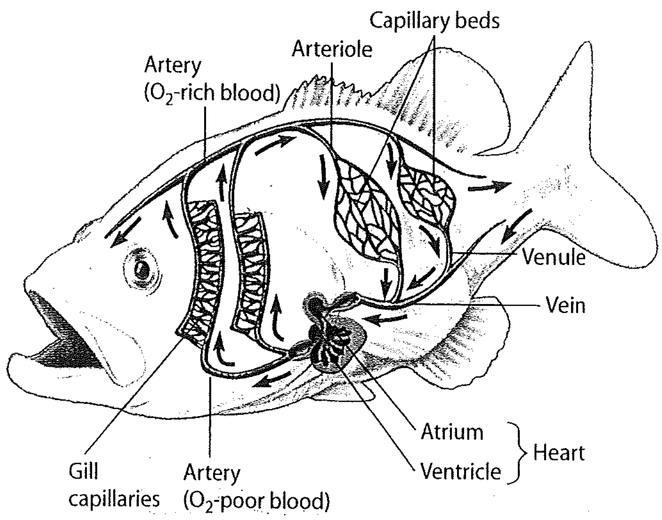
▲ **Figure 13.1A** The open circulatory system of a grasshopper

Earthworms, squids, octopuses, and vertebrates (such as ourselves and giraffes) all have a **closed circulatory system.** It is called "closed" because the circulatory fluid, **blood,** is confined to vessels, keeping it distinct from the interstitial fluid. There are three kinds of vessels: **Arteries** carry blood away from the heart to body organs and tissues; **veins** return blood to the heart; and **capillaries** convey blood between arteries and veins within each tissue. The vertebrate circulatory system is often called a **cardiovascular system** (from the Greek *kardia*, heart, and Latin *vas*, vessel). How extensive are the vessels in your cardiovascular system? If all your blood vessels were lined up end to end, they would circle Earth's equator twice.

The cardiovascular system of a fish **(Figure 13.1B)** illustrates some key features of a closed circulatory system. The heart of a fish has two main chambers. The **atrium** (plural, *atria*) receives blood from the veins, and the **ventricle** pumps blood to the gills via large arteries. As in all figures depicting closed circulatory systems in this book, red represents oxygen-rich blood and blue represents oxygen-poor blood. After passing through the gill capillaries, the blood, now oxygen-rich, flows into large arteries that carry it to all other parts of the body. The large arteries branch into **arterioles,** small vessels that give rise to capillaries. Networks of capillaries called **capillary beds** infiltrate every organ and tissue in the body. The thin walls of the capillaries allow chemical exchange between the blood and the interstitial fluid. The capillaries converge into **venules,** which in turn converge into larger veins that return blood to the heart.

? What are the key differences between an open circulatory system and a closed circulatory system?

The vessels in an open circulatory system do not form an enclosed circuit from the heart, through the body, and back to the heart, and the circulatory fluid is not distinct from interstitial fluid, as is the blood in a closed circulatory system.



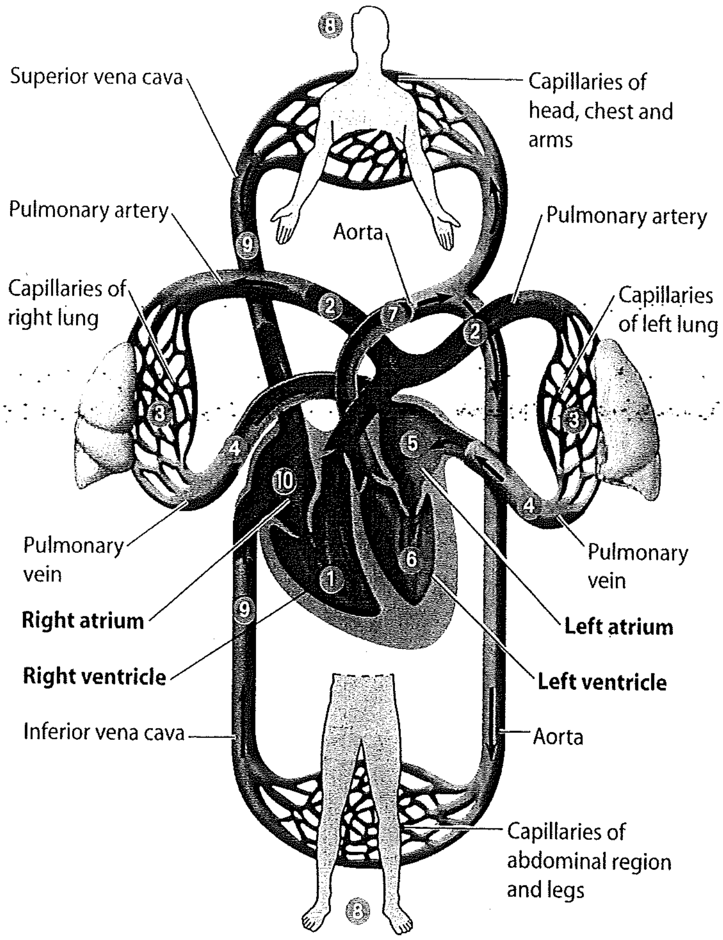
▲ **Figure 13.1B** The closed circulatory system of a fish

The Human Cardiovascular System and Heart

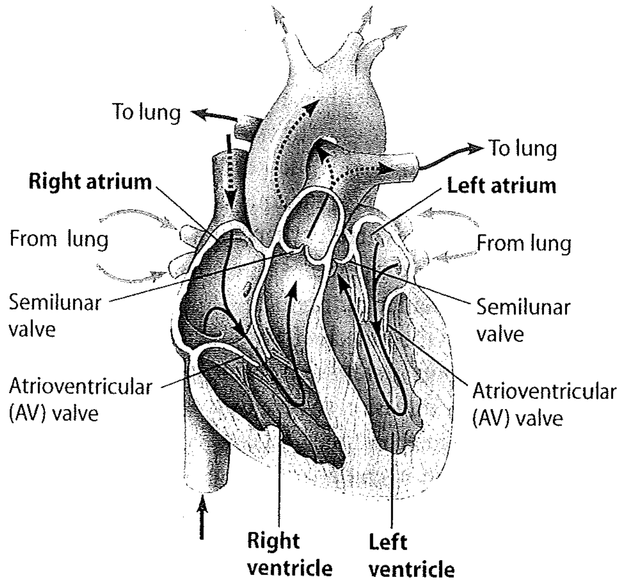
13.2 The human cardiovascular system illustrates the double circulation of mammals

Let's follow the flow of blood through the human circulatory system. Starting in the right ventricle in **Figure 13.2A**, we trace the pulmonary circuit first. (1) The right ventricle pumps oxygen-poor blood to the lungs via (2) the **pulmonary arteries**. As blood flows through (3) capillaries in the lungs, it takes up O_2 and unloads CO_2. Oxygen-rich blood flows back through (4) the **pulmonary veins** to (5) the left atrium. Next, the oxygen-rich blood flows from the left atrium into (6) the left ventricle.

Now let's trace the systemic circuit. As Figure 13.2A shows, the left ventricle pumps oxygen-rich blood into (7) the **aorta**. The aorta is our largest blood vessel, with a diameter of about 2.5 cm, roughly equal to the diameter of a quarter. The first branches from the aorta are the coronary arteries (not shown), which supply blood to the heart muscle itself. Next there are large branches leading to (8) the head, chest, and arms, and the abdominal regions and legs. For simplicity, Figure 13.2A does not show the individual organs, but within each organ, arteries lead to arterioles that branch into capillaries. The capillaries rejoin as venules, which lead to veins. (9) Oxygen-poor blood from the upper part of the body is channeled into a large vein called the **superior vena cava**, and from the lower part of the body it flows through the **inferior vena cava**. The two venae cavae empty into (10) the right atrium. As the blood flows from the right atrium into the right ventricle, we complete our journey, only to start the pulmonary circuit again at the right ventricle.



▲ **Figure 13.2A** Blood flow through the double circulation of the human cardiovascular system



▲ **Figure 13.2B** Blood flow through the human heart

Remember that the path of any single red blood cell is always heart to lung capillaries to heart to body tissue capillaries and back to heart. In one systemic circuit, a blood cell may travel to the brain; in the next (after a pulmonary circuit), it may travel to the legs. A red blood cell never travels from the brain to the legs without first returning to the heart and being pumped to the lungs to be recharged with oxygen.

Figure 13.2B shows the path of blood through the human heart. About the size of a clenched fist, your heart is enclosed in a sac just under the sternum (breastbone). The heart is formed mostly of cardiac muscle tissue. Its thin-walled atria collect blood returning to the heart. The thicker-walled ventricles pump blood to the lungs and to all other body tissues. Notice that the left ventricle walls are thicker than the right, a reflection of how much farther it pumps blood in the body. Flap-like valves between the atria and ventricles and at the openings to the pulmonary artery and the aorta regulate the direction of blood flow. We'll look at these valves and the functioning of the heart in the next module.

? Why does blood in the pulmonary veins have more O_2 than blood in the venae cavae, which are also veins?

Pulmonary veins carry blood from the lungs, where it picks up O_2, to the heart. The venae cavae carry blood returning to the heart after delivering O_2 to the body tissues.

13.3 The heart contracts and relaxes rhythmically

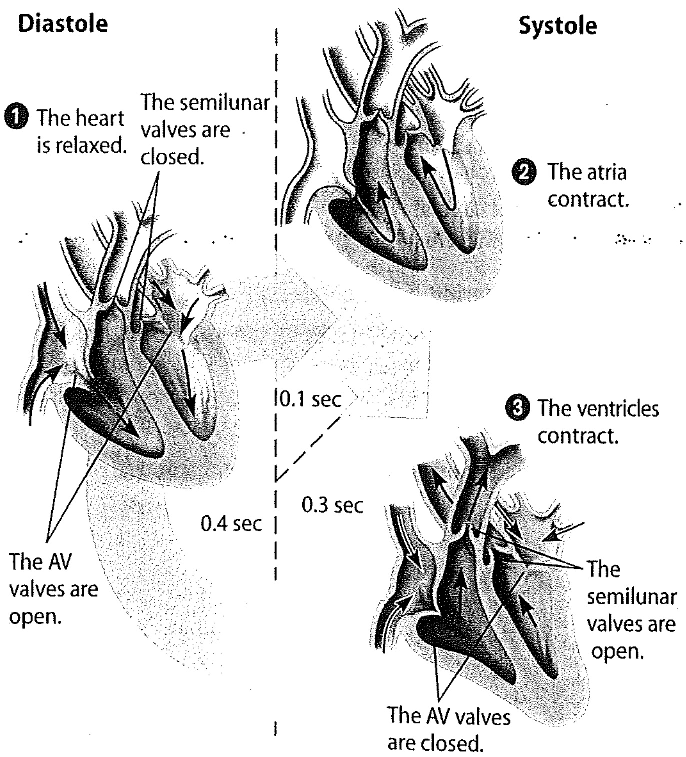
The four-chambered heart is the hub of the circulatory system. It separately but simultaneously pumps oxygen-poor blood to the lungs and oxygen-rich blood to the body. Its pumping action occurs as a rhythmic sequence of contraction and relaxation, called the **cardiac cycle.** When the heart contracts, it pumps blood; when it relaxes, blood fills its chambers.

The Cardiac Cycle How long does a cardiac cycle take? If you have a heart rate of 72 beats per minute, your cardiac cycle takes about 0.8 second. **Figure 13.3** shows that when the heart is relaxed, in the phase called ❶ **diastole**, blood flows into all four of its chambers. Blood enters the right atrium from the venae cavae and the left atrium from the pulmonary veins (see Figure 13.2A). The valves between the atria and the ventricles (atrioventricular, or AV, valves) are open. The valves leading from the ventricles to the aorta or pulmonary artery (semilunar valves) are closed. Diastole lasts about 0.4 second, during which the ventricles nearly fill with blood.

The contraction phase of the cardiac cycle is called **systole.** ❷ Systole begins with a very brief (0.1-second) contraction of the atria that completely fills the ventricles with blood (atrial systole). ❸ Then the ventricles contract for about 0.3 second (ventricular systole). The force of their contraction closes the AV valves, opens the semilunar valves located at the exit from each ventricle, and pumps blood into the large arteries. Blood flows into the relaxed atria during the second part of systole, as the green arrows in step 3 indicate.

Because it pumps blood to your whole body, the left ventricle contracts with greater force than the right. Both ventricles, however, pump the same volume of blood. The volume of blood that each ventricle pumps per minute is called **cardiac output**. This volume is equal to the amount of blood pumped each time a ventricle contracts (about 70 mL, or a little more than $\frac{1}{4}$ cup, for the average person) times the **heart rate** (number of beats per minute). At an average resting heart rate of 72 beats per minute, cardiac output would be calculated as 70 mL/beat $\times$ 72 beats/min = about 5 L/min, roughly equivalent to the total volume of blood in your body. Thus, a drop of blood can travel the entire systemic circuit in just 1 minute.

Heart rate and cardiac output vary, depending on age, fitness, and other factors. Both increase, for instance, during heavy exercise, in which cardiac output can increase fivefold, enabling the circulatory system to provide the additional oxygen needed by hardworking muscles. A well-trained athlete's heart may strengthen and enlarge with a resulting increase in the volume of blood a ventricle pumps. Thus, a resting heart rate of an athlete may be as low as 40 beats/min and still produce a normal cardiac output of about 5 L/min. During competition, a trained athlete's cardiac output may increase sevenfold.



▲ **Figure 13.3** A cardiac cycle in a human with a heart rate of about 72 beats a minute

Heart Valves Notice again in Figure 13.3 how the heart valves act as one-way doors at the exits of the atria and ventricles during a cardiac cycle. Made of flaps of connective tissue, these valves open when pushed from one side and close when pushed from the other. The powerful contraction of the ventricles forces blood against the AV valves, which closes them and keeps blood from flowing back into the atria. The semilunar valves are pushed open when the ventricles contract. When the ventricles relax, blood in the arteries starts to flow back toward the heart, causing the flaps of the semilunar valves to close and preventing blood from flowing back into the ventricles.

You can follow the closing of the two sets of heart valves either with a stethoscope or by pressing your ear tightly against the chest of a friend. The sound pattern is "lub-dup, lub-dup, lub-dup." The "lub" sound comes from the recoil of blood against the closed AV valves. The "dup" is produced by the recoil of blood against the closed semilunar valves.

Someone who is trained can detect the hissing sound of a **heart murmur**, which may indicate a defect in one or more of the heart valves. A murmur occurs when a stream of blood squirts backward through a valve. Some people are born with murmurs, while others have their valves damaged by infection (from rheumatic fever, for instance). Most valve defects do not reduce the efficiency of blood flow enough to warrant surgery. Those that do can be corrected by replacing the damaged valves with synthetic ones or with valves taken from an organ donor (human or other animal).

? **During a cardiac cycle of 0.8 second, the atria are generally relaxed for ______ second.**

0.7

CHAPTER 13 REVIEW

Reviewing the Concepts

Circulatory Systems (13.1)

13.1 Circulatory systems facilitate exchange with all body tissues. Gastrovascular cavities function in both digestion and transport. In open circulatory systems, a heart pumps fluid through open-ended vessels to bathe tissue cells directly. In closed circulatory systems, a heart pumps blood, which travels through arteries to capillaries to veins and back to the heart.

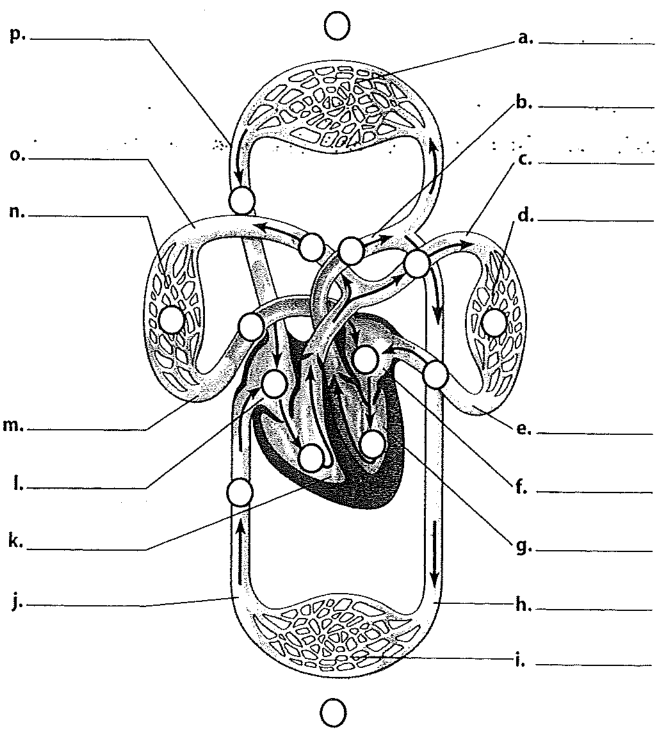
The Human Cardiovascular System and Heart (13.2–13.3)

13.2 The human cardiovascular system illustrates the double circulation of mammals. The mammalian heart has two thin-walled atria and two thick-walled ventricles. The right side of the heart receives and pumps oxygen-poor blood; the left side receives oxygen-rich blood from the lungs and pumps it to all other organs.

13.3 The heart contracts and relaxes rhythmically. During diastole of the cardiac cycle, blood flows from the veins into the heart chambers; during systole, contractions of the atria push blood into the ventricles, and then stronger contractions of the ventricles propel blood into the large arteries. Cardiac output is the amount of blood per minute pumped by a ventricle. Heart valves prevent the backflow of blood.

Connecting the Concepts

1. Use the following diagram to review the flow of blood through a human cardiovascular system. Label the indicated parts, highlight the vessels that carry oxygen-rich blood, and then trace the flow of blood by numbering the circles from 1 to 10, starting with 1 in the right ventricle. (When two locations are equivalent in the pathway, such as right and left lung capillaries or capillaries of top and lower portion of the body, assign them both the same number.)



Testing Your Knowledge

Multiple Choice

2. Which of the following is the main difference between your cardiovascular system and that of a fish?
   a. In a fish, blood is oxygenated by passing through a capillary bed.
   b. Your heart has two chambers; a fish heart has four.
   c. Your circulation has two circuits; fish circulation has one.
   d. Your heart chambers are called atria and ventricles.
   e. Yours is a closed system; the fish's is an open system.

3. Tariq's blood pressure is 150/90. The 150 indicates ______, and the 90 indicates ______.
   a. pressure in the left ventricle; pressure in the right ventricle
   b. arterial pressure; heart rate
   c. pressure during ventricular contraction; pressure during heart relaxation
   d. systemic circuit pressure; pulmonary circuit pressure
   e. pressure in the arteries; pressure in the veins

4. Blood flows more slowly in the arterioles than in the artery that supplies them because the arterioles
   a. must provide opportunity for exchange with the interstitial fluid.
   b. have thoroughfare channels to venules that are often closed off, slowing the flow of blood.
   c. have sphincters that restrict flow to capillary beds.
   d. are narrower than the artery.
   e. collectively have a larger cross-sectional area than does the artery.

5. Which of the following is *not* a true statement about open and closed circulatory systems?
   a. Both systems have some sort of a heart that pumps a circulatory fluid through the body.
   b. A frog has an open circulatory system; other vertebrates have closed circulatory systems.
   c. The blood and interstitial fluid are separate in a closed system but are indistinguishable in an open system.
   d. The open circulatory system of an insect does not transport O_2 to body cells; closed circulatory systems do transport O_2.
   e. Some of the circulation of blood in both systems results from body movements.

Describing, Comparing, and Explaining

6. Trace the path of blood starting in a pulmonary vein, through the heart, and around the body, returning to the pulmonary vein. Name, in order, the heart chambers and types of vessels through which the blood passes.

Answers to all questions can be found in Appendix 1.

CHAPTER

14 Reproduction and Embryonic Development

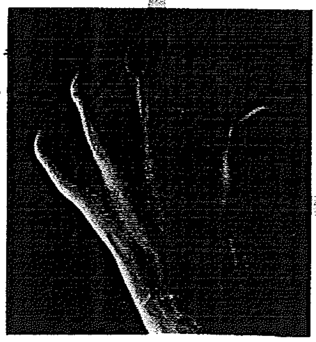
BIG IDEAS

Asexual and Sexual Reproduction
(14.1–14.2)

Some animals can reproduce asexually, but most reproduce by the fusion of egg and sperm.

Human Reproduction
(14.3–14.5)

Human males and females have structures that produce, store, and deliver gametes.



Principles of Embryonic Development
(14.6–14.8)

A zygote develops into an embryo through a series of carefully regulated processes.

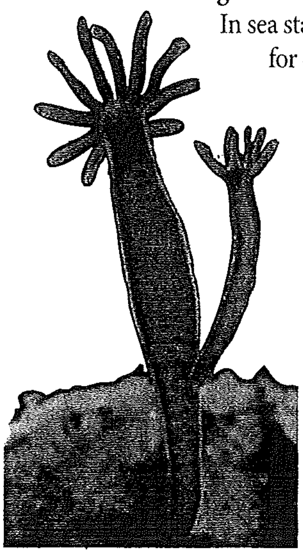
Asexual and Sexual Reproduction

14.1 Asexual reproduction results in the generation of genetically identical offspring

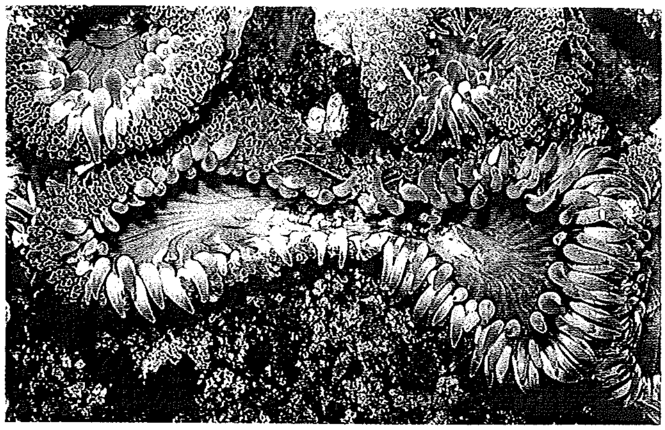
Individual animals have a finite life span. A species transcends this limit only by **reproduction**, the creation of new individuals from existing ones. Animals reproduce in a great variety of ways, but there are two principal modes: asexual and sexual.

Asexual reproduction (reproduction without sex) is the creation of genetically identical offspring by a lone parent. Because asexual reproduction proceeds without the fusion of egg and sperm, the resulting offspring are genetic copies of the one parent.

Several types of asexual reproduction are found among animals. Many invertebrates, such as the hydra in **Figure 14.1A**, reproduce asexually by **budding**, splitting off new individuals from outgrowths of existing ones. The sea anemone in the center of **Figure 14.1B** is undergoing **fission**, the separation of a parent into two or more individuals of about equal size. Asexual reproduction can also result from the process of **fragmentation**, the breaking of the parent body into several pieces, followed by **regeneration**, the regrowth of lost body parts. In sea stars (starfish) of the genus *Linckia*, for example, a whole new individual can develop from a broken-off arm plus a bit of the central body. Thus, a single animal with five arms, if broken apart, could potentially give rise to five offspring via asexual reproduction in a matter of weeks. In some species of sea sponges, if a single sponge is pushed through a wire mesh, each of the resulting clumps of cells can regrow into a new sponge. (Besides the natural means of asexual reproduction discussed here, many species have been the target of artificial asexual reproduction.)



▲ **Figure 14.1A** Asexual reproduction via budding in a hydra



▲ **Figure 14.1B** Asexual reproduction of a sea anemone (*Anthopleura elegantissima*) by fission

In nature, asexual reproduction has several potential advantages. For one, it allows animals that do not move from place to place or that live in isolation to produce offspring without finding mates. Another advantage is that it enables an animal to produce many offspring quickly; no time or energy is lost in production of eggs and sperm or in mating. Asexual reproduction perpetuates a particular genotype faithfully, precisely, and rapidly. Therefore, it can be an effective way for animals that are genetically well suited to an environment to quickly expand their populations and exploit available resources.

A potential disadvantage of asexual reproduction is that it produces genetically uniform populations. Genetically similar individuals may thrive in one particular environment, but if the environment changes and becomes less favorable, all individuals may be affected equally, and the entire population may die out.

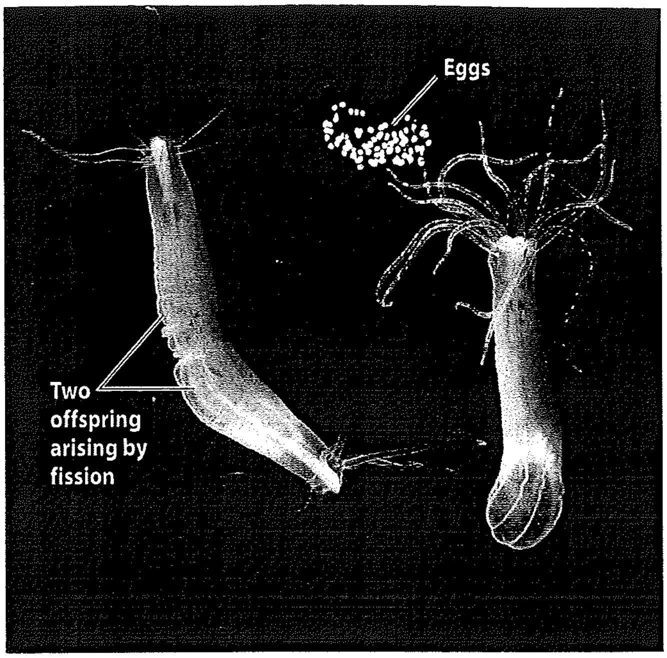
? What kinds of environments would likely be advantageous to asexually reproducing organisms? Why?

Relatively unchanging environments favor asexual reproduction because well-suited individuals can rapidly multiply and use available resources.

14.2 Sexual reproduction results in the generation of genetically unique offspring

Sexual reproduction is the creation of offspring through the process of **fertilization**, the fusion of two haploid (n) sex cells, or **gametes**, to form a diploid ($2n$) **zygote** (fertilized egg). (Recall from Chapter 7 that n refers to the haploid number of chromosomes and $2n$ refers to the diploid number; for humans, $n = 23$ and $2n = 46$.) The male gamete, the **sperm**, is a relatively small cell that moves by means of a flagellum. The female gamete, the **egg**, is a much larger cell that is not self-propelled. The zygote—and the new individual it develops into—contains a unique combination of genes inherited from the parents via the egg and sperm.

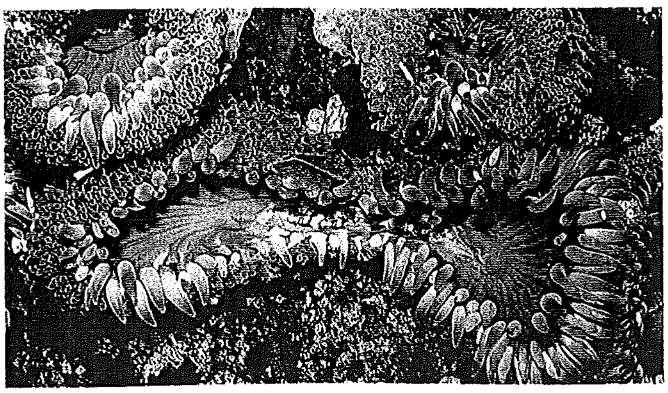
Most animals reproduce mainly or exclusively by sexual reproduction, which increases genetic variability among offspring. Meiosis and random fertilization can generate enormous genetic variation. And such variation is the raw material of development by natural selection. The variability produced by the reshuffling of genes in sexual reproduction may provide greater adaptability to changing environments. According to this hypothesis, when an environment changes suddenly or drastically, more offspring will survive and reproduce if they aren't all genetically very similar.



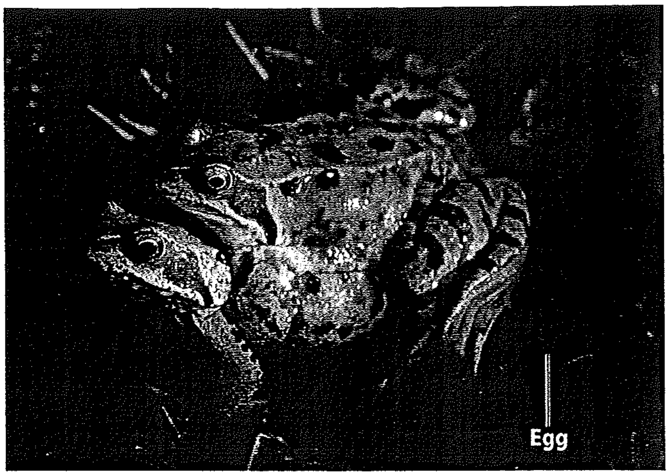
▲ **Figure 14.2A** Asexual (left) and sexual (right) reproduction in the starlet sea anemone (*Nematostella vectensis*)

Animals that can reproduce both asexually and sexually benefit from both modes. In **Figure 14.2A**, you can see two sea anemones of the same species; the one on the left is reproducing asexually (via fission) while the one on the right is releasing eggs. Many other marine invertebrates can also reproduce by both modes. Why would such dual reproductive capabilities be advantageous to an organism? From several well-studied cases, it is known that certain animals reproduce asexually when there is ample food and when water temperatures are favorable for rapid growth and development. Asexual reproduction usually continues until cold temperatures signal the approach of winter or until the food supply dwindles or the habitat starts to dry up. At that point, the animals switch to a sexual reproduction mode, resulting in a generation of genetically varied individuals with better potential to adapt to the changing conditions.

Although sexual reproduction has advantages, it presents a problem for nonmobile animals and for those that live solitary lives: how to find a mate. One solution that has developed is **hermaphroditism**, in which each individual has both female and male reproductive systems. (The term comes from the Greek myth in which Hermaphroditus, the son of the gods Hermes and Aphrodite, fused with a woman to form one individual of both sexes.) Although some hermaphrodites, such as



▲ **Figure 14.2B** Hermaphroditic earthworms mating



▲ **Figure 14.2C** Frogs in an embrace that triggers the release of eggs and sperm (the sperm are too small to be seen)

tapeworms, can fertilize their own eggs, most must mate with another member of the same species. When hermaphrodites mate (for example, the two earthworms in **Figure 14.2B**), each animal serves as both male and female, donating and receiving sperm. For hermaphrodites, there is only one sex, so every individual encountered is a potential mate. Mating can therefore result in twice as many offspring than if only one individual's eggs were fertilized.

The mechanics of fertilization play an important part in sexual reproduction. Many aquatic invertebrates and most fishes and amphibians exhibit **external fertilization**: The parents discharge their gametes into the water, where fertilization then occurs, often without the male and female even making physical contact. Timing is crucial because the eggs and sperm must be available for fertilization at the same time. For many species—certain clams that live in freshwater rivers and lakes, for instance—environmental cues such as temperature and day length cause a whole population to release gametes all at once. Males or females may also emit a chemical signal as they release their gametes. The signal triggers gamete release in members of the opposite sex. Most fishes and amphibians with external fertilization have specific courtship rituals that trigger simultaneous gamete release in the same vicinity by the female and male. An example of such a mating ritual is the clasping of a female frog by a male **(Figure 14.2C)**.

In contrast to external fertilization, **internal fertilization** occurs when sperm are deposited in or close to the female reproductive tract and gametes unite within the tract. Nearly all terrestrial animals exhibit internal fertilization, which is an adaptation that enables sperm to reach an egg despite a dry external environment. Internal fertilization usually requires **copulation**, or sexual intercourse. It also requires complex reproductive systems, including organs for gamete storage and transport and organs that facilitate copulation. For examples of these complex structures, we turn next to the human female and male.

? In terms of genetic makeup, what is the most important difference between the outcome of sexual reproduction and that of asexual reproduction?

The offspring of sexual reproduction are genetically diverse, whereas the offspring of asexual reproduction are genetically identical.

Human Reproduction

14.3 Reproductive anatomy of the human female

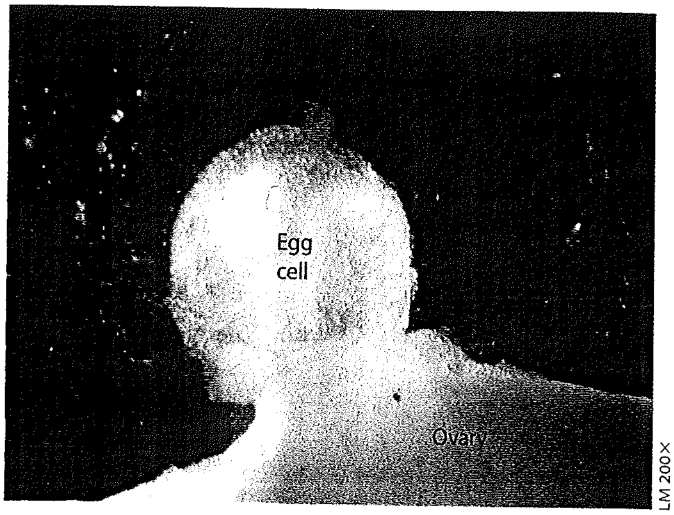
Although we tend to focus on the anatomical differences between the human male and female reproductive systems, there are also some important similarities. Both sexes have a pair of **gonads**, the organs that produce gametes. Also, both sexes have ducts that store and deliver gametes as well as structures that facilitate copulation. In this and the next module, we examine the anatomical features of the human reproductive system, beginning with female anatomy.

A woman's gonads, her **ovaries**, are each about an inch long, with a bumpy surface (**Figure 14.3A**). The bumps are **follicles**, each consisting of one or more layers of cells that surround, nourish, and protect a single developing egg cell. In addition to producing egg cells, the ovaries produce hormones. Specifically, the follicle cells produce the female sex hormone estrogen. (In this chapter, we use the word *estrogen* to refer collectively to several closely related chemicals that affect the body similarly.)

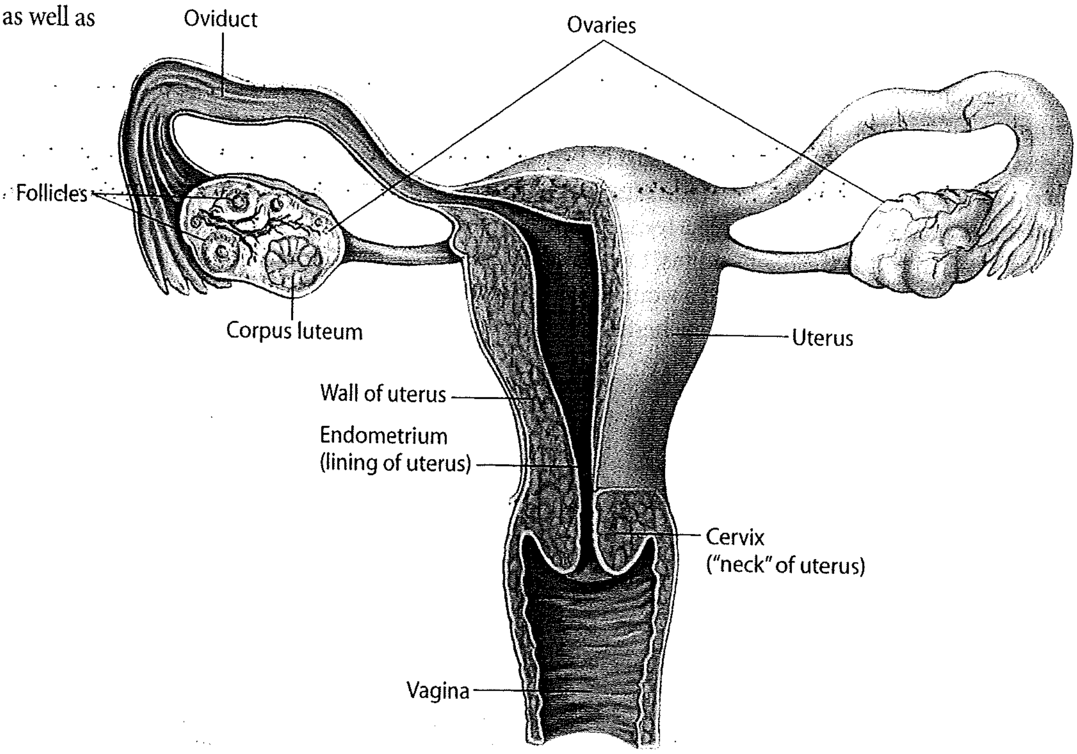
A female is born with 1–2 million follicles, but only several hundred will release egg cells during her reproductive years. Starting at puberty, one follicle (or, rarely, more than one) matures and releases an immature egg cell about every 28 days. This monthly cycle continues until a female reaches menopause, which usually occurs around age 50. An immature egg cell is ejected from the follicle in a process called **ovulation**, shown in **Figure 14.3B**.

After ovulation, the follicular tissue that had been surrounding the egg that was just ejected grows within the ovary to form a solid mass called the **corpus luteum**; you can see one in the ovary on the left in Figure 14.3A. The corpus luteum secretes additional estrogen as well as progesterone, a hormone that helps maintain the uterine lining during pregnancy. If the released egg is not fertilized, the corpus luteum degenerates, and a new follicle matures during the next cycle. We discuss ovulation and female hormonal cycles further in later modules.

Notice in Figure 14.3A that each ovary lies next to the opening of an **oviduct**, also called a fallopian tube. The oviduct opening resembles a funnel fringed with finger-like projections. The projections touch the surface of the ovary, but the ovary is



▲ **Figure 14.3B** Ovulation



▲ **Figure 14.3A** Front view of female reproductive anatomy (upper portion)

actually separated from the opening of the oviduct by a tiny space. When ovulation occurs, the egg cell passes across the space and into the oviduct, where cilia sweep it toward the uterus. If sperm are present, fertilization may occur in the upper part of the oviduct. The resulting zygote starts to divide, thus becoming an embryo, as it moves along within the oviduct.

The **uterus**, also known as the womb, is the actual site of pregnancy. The uterus is only about 3 inches long in a woman who has never been pregnant, but during pregnancy it expands considerably as the baby develops. The uterus has a thick muscular wall, and its inner lining, the **endometrium**, is richly supplied with blood vessels. An embryo implants in the endometrium, and development is completed there. The term **embryo** is used for the stage in development from the first division of the zygote until body structures begin to appear, about the 9th week in humans. From the 9th week until birth, a developing human is called a **fetus**.

The uterus is the normal site of pregnancy. However, in about 1% of pregnancies, the embryo implants somewhere else, resulting in an **ectopic pregnancy**. Most ectopic pregnancies occur in the oviduct and are called tubal pregnancies. An ectopic pregnancy is a serious medical emergency that requires surgical intervention; otherwise, it can rupture surrounding tissues, causing severe bleeding and even death of the mother.

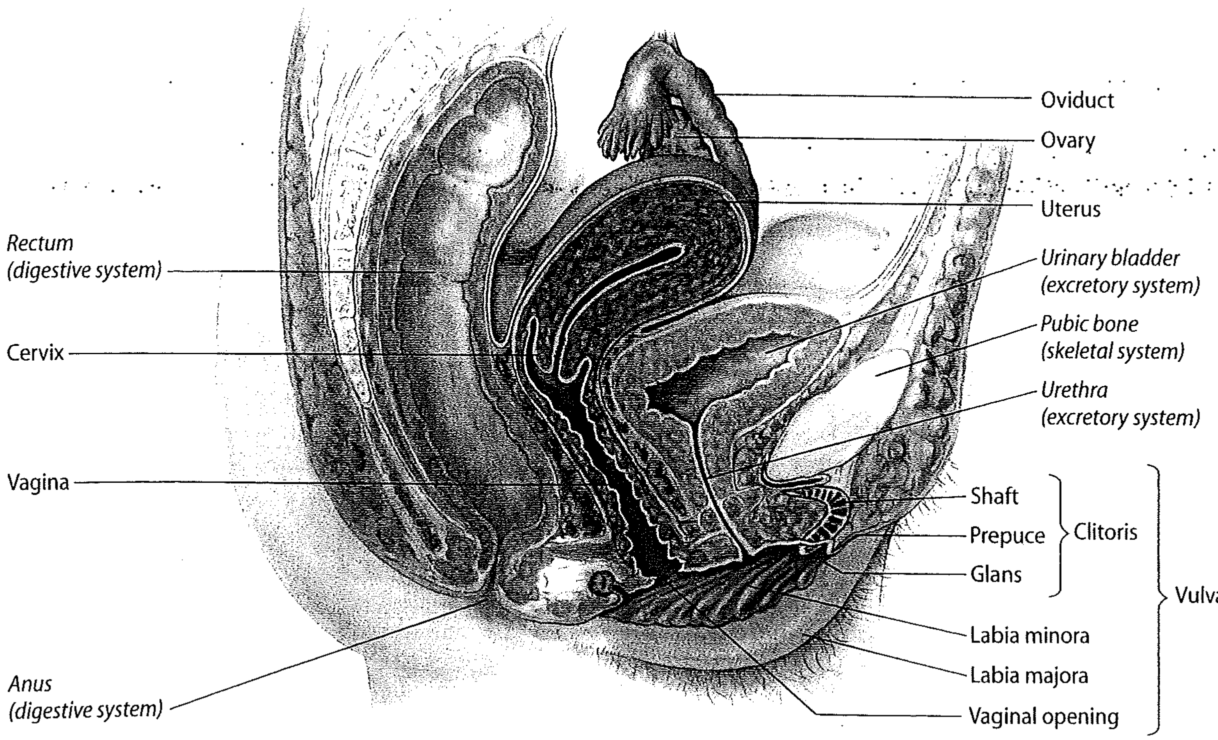
The narrow neck at the bottom of the uterus is the **cervix**, which opens into the vagina. It is recommended that women have a yearly Pap test in which cells are removed from around the cervix and examined under a microscope for signs of cervical cancer. Regular Pap smears greatly increase the chances of detecting cervical cancer early and therefore treating it successfully. The cervix opens to the **vagina**, a thin-walled, but strong, muscular chamber that serves as the birth canal through which the baby is born. The vagina is also the repository for sperm during sexual intercourse. Glands near the vaginal opening secrete mucus during sexual arousal, lubricating the vagina and facilitating intercourse.

You can see more features of female reproductive anatomy in **Figure 14.3C**, a side view. **Vulva** is the collective term for the external female genitalia. Notice that the vagina opens to the outside just behind the opening of the urethra, the tube through which urine is excreted. A pair of slender skin folds, the **labia minora**, border the openings, and a pair of thick, fatty ridges, the **labia majora**, protect the vaginal opening. Until sexual intercourse or vigorous physical activity ruptures it, a thin piece of tissue called the hymen partly covers the vaginal opening.

Several female reproductive structures are important in sexual arousal, and stimulation of them can produce highly pleasurable sensations. The vagina, labia minora, and a small erectile organ called the **clitoris** all engorge with blood and enlarge during sexual activity. The clitoris consists of a short shaft supporting a rounded **glans**, or head, covered by a small hood of skin called the **prepuce**. In Figure 14.3C, blue highlights the spongy erectile tissue within the clitoris that fills with blood during arousal. The clitoris, especially the glans, has an enormous number of nerve endings and is very sensitive to touch. Keep in mind the details of female reproductive anatomy as you read the next module, and you'll notice many similarities in the human male.

? Where does fertilization occur? In which organ does the fetus develop?

The oviduct; the uterus.



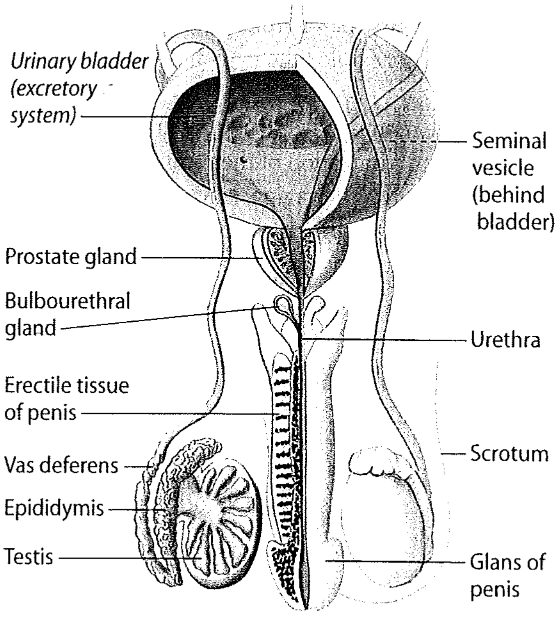
▲ **Figure 14.3C** Side view of female reproductive anatomy (with nonreproductive structures in italic)

14.4 Reproductive anatomy of the human male

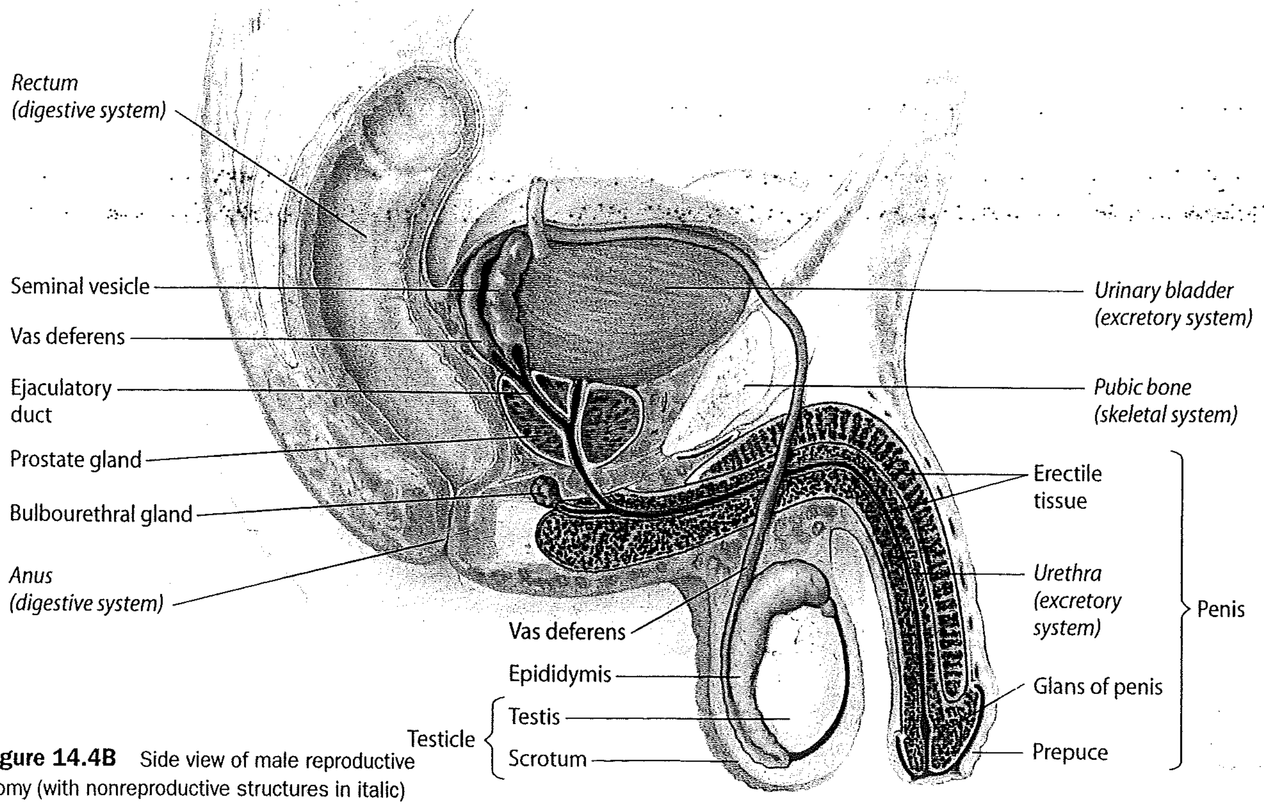
Figures 14.4A and **14.4B** present front and side views of the male reproductive system. The male gonads, or **testes** (singular, *testis*), are each housed outside the abdominal cavity in a sac called the **scrotum**. A testis and scrotum together are called a **testicle**. Sperm cannot develop optimally at human core body temperature; the scrotum keeps the sperm-forming cells about 2°C cooler, which allows them to function normally. In cold conditions, muscles around the scrotum contract, pulling the testes toward the body, thereby maintaining the proper temperature.

Now let's track the path of sperm from one of the testes out of the male's body. From each testis, sperm pass into a coiled tube called the **epididymis**, which stores the sperm while they continue to develop. Sperm leave the epididymis during **ejaculation**, the expulsion of sperm-containing fluid from the penis. At that time, muscular contractions propel the sperm from the epididymis through another duct called the **vas deferens**. The vas deferens passes upward into the abdomen and loops around the urinary bladder. Next to the bladder, the vas deferens joins a short duct from a gland, the seminal vesicle. The two ducts unite to form a short **ejaculatory duct**, which joins its counterpart conveying sperm from the other testis. Each ejaculatory duct empties into the urethra, which conveys both urine and sperm out through the penis, although not at the same time. Thus, unlike the female, the male has a direct connection between the reproductive and urinary systems.

In addition to the testes and ducts, the reproductive system of human males contains three sets of glands: the seminal vesicles, the prostate gland, and the bulbourethral glands. The two **seminal vesicles** secrete a thick fluid that contains fructose, which provides most of the energy used by the sperm as they propel themselves through the female reproductive tract. The **prostate gland** secretes a thin fluid that further nourishes the sperm. The two **bulbourethral glands** secrete a clear, alkaline mucus.



▲ **Figure 14.4A** Front view of male reproductive anatomy

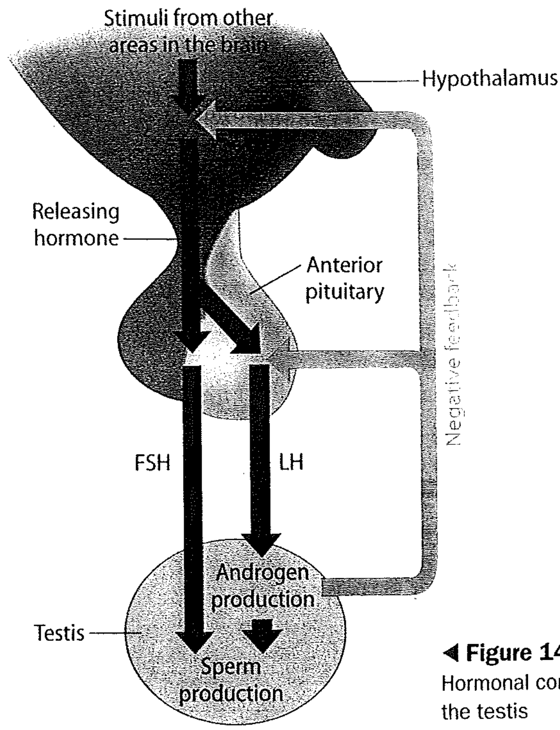


▲ **Figure 14.4B** Side view of male reproductive anatomy (with nonreproductive structures in italic)

Together, the sperm and the glandular secretions make up **semen**, the fluid ejaculated from the penis during **orgasm**, a series of rhythmic, involuntary contractions of the reproductive structures. About 2–5 mL (1 teaspoonful) of semen are discharged during a typical ejaculation. About 95% of the fluid consists of glandular secretions. The other 5% is made up of sperm (typically 200–500 million of them), only one of which may eventually fertilize an egg. The alkalinity of the semen balances the acidity of any traces of urine in the urethra and neutralizes the acidic environment of the vagina, protecting the sperm and increasing their motility.

The human **penis** consists mainly of erectile tissue (shown in blue in Figures 14.4A and 14.4B) that can fill with blood to cause an erection during sexual arousal. Erection is essential for insertion of the penis into the vagina. Like the clitoris, the penis consists of a shaft that supports the glans, or head. The glans is richly supplied with nerve endings and is highly sensitive to stimulation. A fold of skin called the prepuce, or foreskin, covers the glans. Circumcision, the surgical removal of the prepuce, arose from religious traditions. Recent studies have suggested that circumcision does have a medical advantage: The procedure significantly reduces a man's chance of contracting and passing on sexually transmitted diseases, including AIDS.

Ejaculation occurs in two stages. 1 At the peak of sexual arousal, muscle contractions in multiple glands force secretions into the urethra and propel sperm from the epididymis. At the same time, a sphincter muscle at the base of the bladder contracts, preventing urine from leaking into the urethra from the bladder. Another sphincter also contracts, closing off the entrance of the urethra into the penis. The section of the urethra between the two sphincters fills with semen and expands. 2 In the second stage of ejaculation, the expulsion stage, the sphincter at the base of the penis relaxes, admitting semen into the penis. At the same time, a series of strong muscle contractions around the base of the penis and along the urethra expels the semen from the body.



◀ **Figure 14.4C** Hormonal control of the testis

Figure 14.4C shows how hormones control sperm production by the testes. The hypothalamus secretes a releasing hormone that regulates release of follicle-stimulating hormone (FSH) and luteinizing hormone (LH) by the anterior pituitary FSH increases sperm production by the testes, while LH promotes the secretion of androgens, mainly testosterone. Androgens stimulate sperm production. In addition, androgens carried in the blood help maintain homeostasis by a negative-feedback mechanism (red arrows), inhibiting secretion of both the releasing hormone and LH. Under the control of this chemical regulating system, the testes produce hundreds of millions of sperm every day, from puberty well into old age. Next we'll see how sperm and eggs are made.

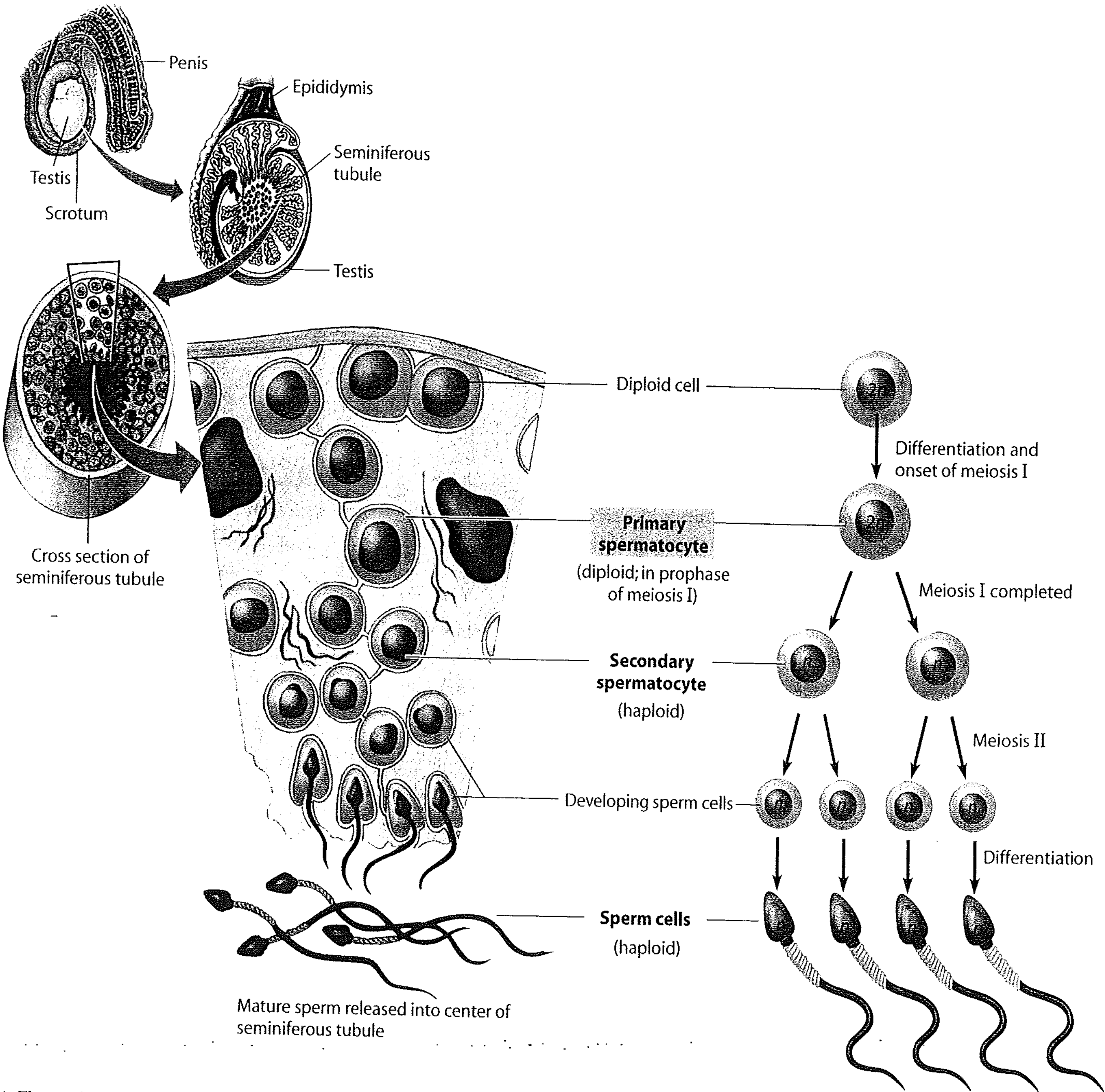
? Arrange the following organs in the correct sequence for the travel of sperm: epididymis, testis, urethra, vas deferens.

Testis, epididymis, vas deferens, urethra.

14.5 The formation of sperm and egg cells requires meiosis

Both sperm and egg are haploid (n) cells that develop by meiosis from diploid ($2n$) cells in the gonads. Recall that the diploid chromosome number in humans is 46; that is, $2n = 46$. Before we turn to the formation of gametes, **gametogenesis**, you may want to review Modules 7.5–7.6 as background for our discussion. There are significant differences in gametogenesis between human males and females, so we'll examine the processes separately.

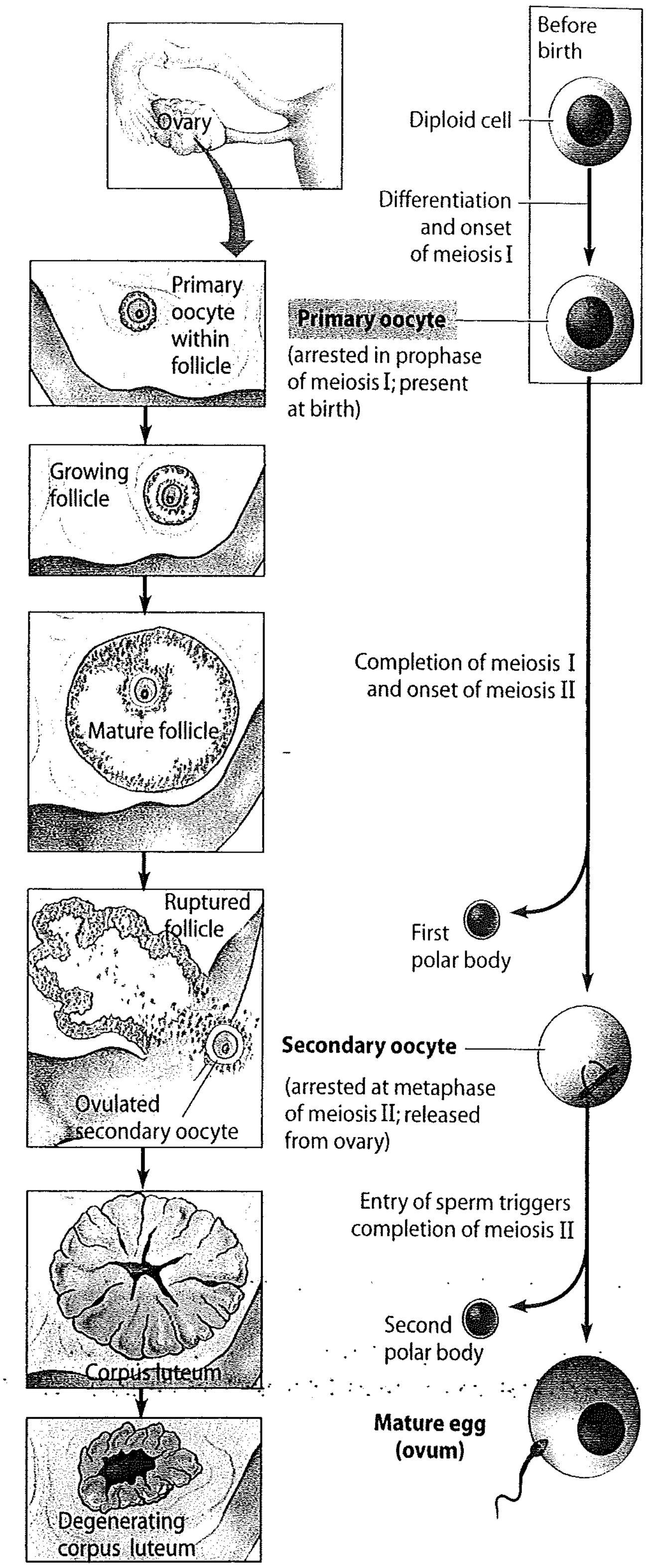
Figure 14.5A outlines **spermatogenesis**, the formation of sperm cells. Sperm develop in the testes in coiled tubes called the **seminiferous tubules**. Diploid cells that begin the process are located near the outer wall of the tubules (at the top of the enlarged wedge of tissue in Figure 14.5A). These cells multiply continuously by mitosis, and each day about 3 million of them differentiate into **primary spermatocytes**, the cells that undergo meiosis. Meiosis I of a primary spermatocyte produces two **secondary spermatocytes**, each with the haploid number of chromosomes ($n = 23$). Meiosis II then forms four cells, each with the haploid number of chromosomes. A sperm cell develops by differentiation of each of these haploid cells and is gradually pushed toward the center of the seminiferous tubule. From there it passes into the epididymis, where it matures, becomes motile, and is stored until ejaculation. In human males, spermatogenesis takes about 10 weeks.



▲ **Figure 14.5A** Spermatogenesis

The right side of **Figure 14.5B** shows **oogenesis**, the development of a mature egg (also called an ovum; plural, *ova*). Most of the process occurs in the ovary. Oogenesis actually begins prior to birth, when a diploid cell in each developing follicle begins meiosis. At birth, each follicle contains a dormant **primary oocyte**, a diploid cell that is resting in prophase of meiosis I. A primary oocyte can be hormonally triggered to develop further. Between puberty and menopause, about every 28 days, FSH (follicle-stimulating hormone) from the pituitary stimulates one of the dormant follicles to develop. The follicle enlarges, and the primary oocyte completes meiosis I and begins meiosis II. Meiosis then halts again at metaphase II.

▲ an



▲ **Figure 14.5B** Oogenesis and the development of an ovarian follicle

In the female, the division of the cytoplasm in meiosis I is unequal, with a single **secondary oocyte** receiving almost all of it. The smaller of the two daughter cells, called the first polar body, receives almost no cytoplasm.

The secondary oocyte is released by the ovary during ovulation. It enters the oviduct, and if a sperm cell penetrates it, the secondary oocyte completes meiosis II. Meiosis II is also unequal, yielding a second polar body and the mature egg (ovum). The haploid nucleus of the mature egg can then fuse with the haploid nucleus of the sperm cell, producing a zygote.

Although not shown in Figure 14.5B, the first polar body may also undergo meiosis II, forming two cells. These and the second polar body receive virtually no cytoplasm and quickly degenerate, leaving the mature egg with nearly all the cytoplasm and thus the bulk of the nutrients contained in the original diploid cell.

The left side of Figure 14.5B is a cutaway view of an ovary. The series of follicles here represents the changes one follicle undergoes over time. An actual ovary would have thousands of dormant follicles, each containing a primary oocyte. Usually, only one follicle has a dividing oocyte at any one time. Meiosis I occurs as the follicle matures. About the time the secondary oocyte forms, the pituitary hormone LH (luteinizing hormone) triggers ovulation, the rupture of the follicle and expulsion of the secondary oocyte. The ruptured follicle then develops into a corpus luteum ("yellow body"). Unless fertilization occurs, the corpus luteum degenerates before another follicle starts to develop.

Oogenesis and spermatogenesis are alike in that they both produce haploid gametes. However, these two processes differ in some important ways. First, only one mature egg results from each diploid cell that undergoes meiosis. The other products of oogenesis, the polar bodies, degenerate. By contrast, in spermatogenesis, all four products of meiosis develop into mature gametes. Second, although the cells from which sperm develop continue to divide by mitosis throughout the male's life, this is probably not the case for the comparable cells in the human female. Third, oogenesis has long "resting" periods, whereas spermatogenesis produces mature sperm in an uninterrupted sequence.

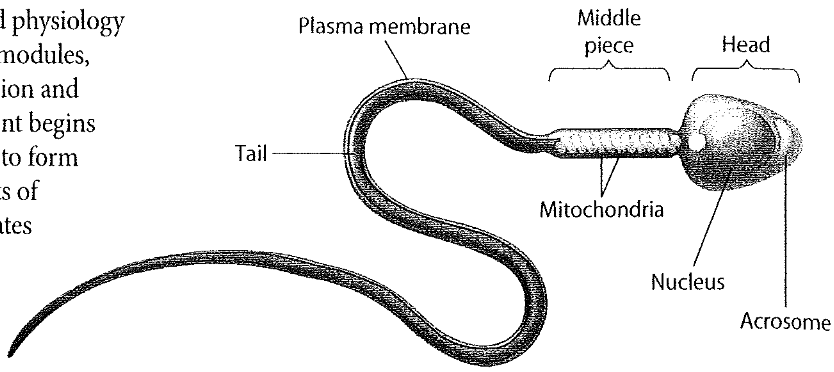
? **Which process in the development of sperm and eggs is responsible for the genetic variation among gametes?**

The random alignment of homologous chromosomes during meiosis, specifically meiosis I.

Principles of Embryonic Development

14.6 Fertilization results in a zygote and triggers embryonic development

The previous modules focused on the anatomy and physiology of the human reproductive system. In the next six modules, we examine the results of reproduction: the formation and development of an embryo. Embryonic development begins with fertilization, the union of a sperm and an egg to form a diploid zygote. Fertilization combines haploid sets of chromosomes from two individuals and also activates the egg by triggering metabolic changes that start embryonic development.



▲ **Figure 14.6B** The structure of a human sperm cell

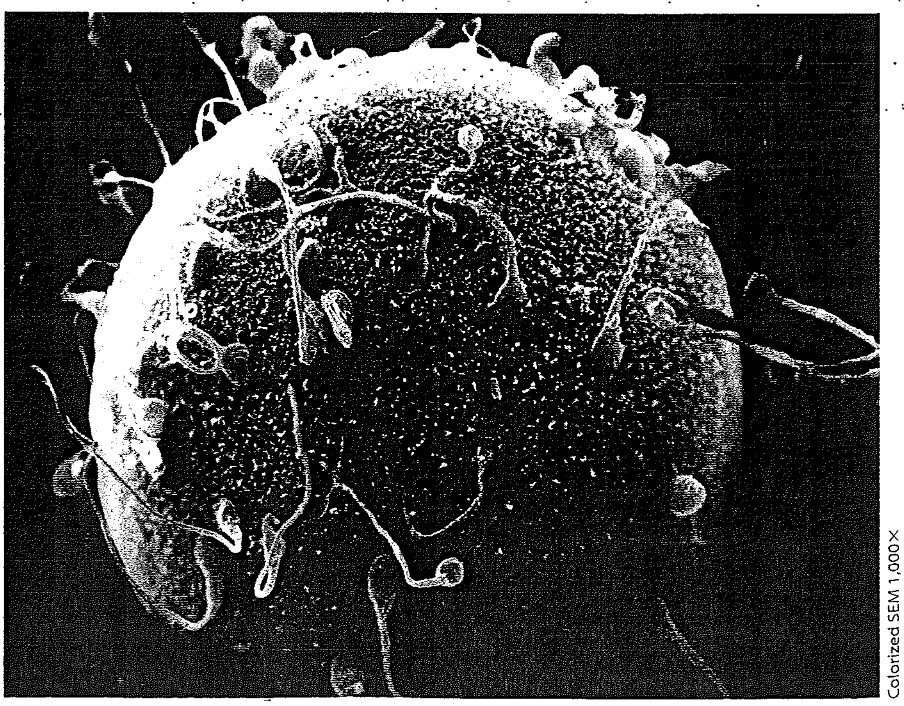
The Properties of Sperm Cells **Figure 14.6A** is a micrograph of an unfertilized human egg that is surrounded by sperm. Among all of these sperm, only one will enter and fertilize the egg. All the other sperm—the ones shown here and millions more that were ejaculated with them—will die. The one sperm that penetrates the egg adds its unique set of genes to those of the egg and contributes to the next generation.

Figure 14.6B illustrates the structure of a mature human sperm cell, a clear case of form fitting function. The sperm's streamlined shape is an adaptation for swimming through fluids in the vagina, uterus, and oviduct of the female. Its thick head contains a haploid nucleus and is tipped with a vesicle, the **acrosome**, which lies just inside the plasma membrane. The acrosome contains enzymes that help the sperm penetrate the egg. The middle piece of the sperm contains mitochondria. The sperm absorbs high-energy nutrients, especially the sugar fructose, from the semen. Thus fueled, its mitochondria provide ATP for movement of the tail, which is actually a flagellum. By the time a sperm has reached the egg, it has consumed much of the energy available to it. But a successful sperm will have enough energy left to penetrate the egg and deposit its nucleus in the egg's cytoplasm.

The Process of Fertilization **Figure 14.6C** illustrates the sequence of events in fertilization. This diagram is based on fertilization in sea urchins, on which a great deal of research has been done. Similar processes occur in other animals, including humans. The diagram traces one sperm through the successive activities of fertilization. Notice that to reach the egg nucleus, the sperm nucleus must pass through three barriers: the egg's jelly coat (yellow), a middle region of glycoproteins called the vitelline layer (pink), and the egg cell's plasma membrane.

Let's follow the steps shown in the figure. 1 The contact of a sperm with the jelly coat of the egg triggers the release from

▶ **Figure 14.6A** A human egg cell surrounded by sperm



the sperm's acrosome of a cloud of enzyme molecules by exocytosis (see Module 4.6). ② The enzyme molecules digest a cavity into the jelly. When the sperm head reaches the vitelline layer, ③ species-specific protein molecules on its surface bind with specific receptor proteins on the vitelline layer. The binding between these proteins ensures that sperm of other species cannot fertilize the egg. This specificity is especially important when fertilization is external because the sperm of other species may be present in the water. After the specific binding occurs, the sperm proceeds through the vitelline layer, and ④ the sperm's plasma membrane fuses with that of the egg. Fusion of the two membranes ⑤ makes it possible for the sperm nucleus to enter the egg.

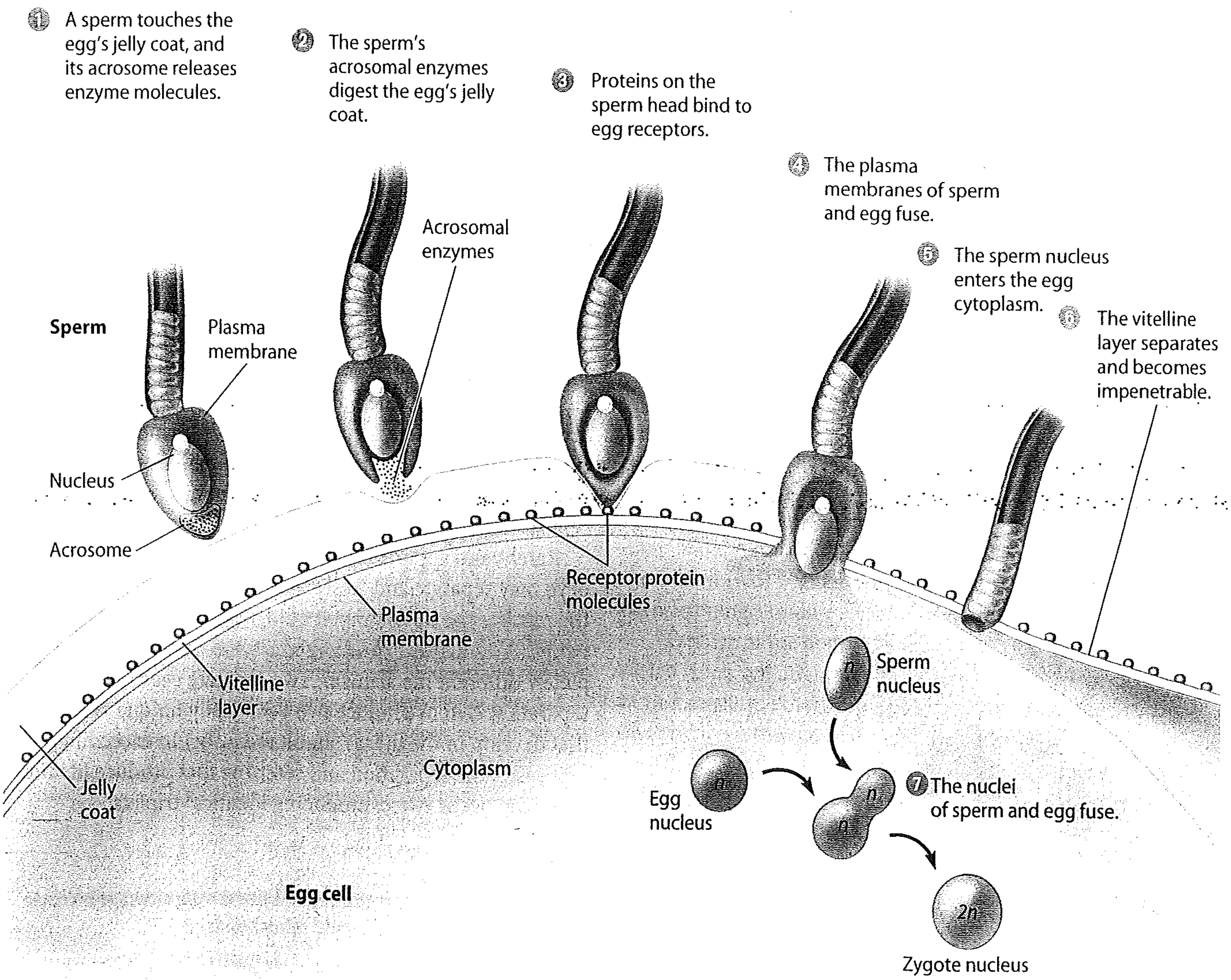
Fusion of the sperm and egg plasma membranes triggers a number of important changes in the egg. Two such changes prevent other sperm from entering the egg. About 1 second after the membranes fuse, the entire egg plasma membrane becomes impenetrable to other sperm cells. Shortly thereafter, ⑥ the vitelline layer hardens and separates from the plasma membrane. The space quickly fills with water, and the vitelline layer becomes impenetrable to sperm. If these events did not occur and an egg were fertilized by more than one sperm, the resulting zygote nucleus would contain too many chromosomes, and the zygote could not develop normally.

⑦ About 20 minutes after the sperm nucleus enters the egg, the sperm and egg nuclei fuse. Gearing up for the enormous growth and development that will soon follow, DNA synthesis and cellular respiration begin. The first cell division occurs after about 90 minutes, marking the end of the fertilization stage.

Note that the sperm provided chromosomes to the zygote, but little else. The zygote's cytoplasm and various organelles were all provided by the mother through the egg. In the next module, we begin to trace the development of the zygote into a new animal.

? Why is the vitelline layer particularly important among aquatic animals that use external fertilization?

Protein receptors on the vitelline layer match with species-specific proteins on the sperm; this ensures that sperm of a different species will not fertilize the egg.



▲ **Figure 14.6C** The process of fertilization in a sea urchin

14.7 Cleavage produces a ball of cells from the zygote

An animal consists of many thousands, millions, even trillions of cells that are precisely organized into complex tissues and organs. The transformation from a zygote to this multicellular state is truly phenomenal. Order and precision are required at every step, and both are clearly displayed in the first two major phases of embryonic development: cleavage and gastrulation.

Cleavage is a rapid succession of cell divisions that produces a ball of cells—a multicellular embryo—from the zygote. Nutrients stored in the egg nourish the dividing cells. DNA replication, mitosis, and cytokinesis occur rapidly, but gene transcription virtually shuts down and few new proteins are synthesized. The embryo does not enlarge significantly; instead, cleavage partitions the cytoplasm of the one-celled zygote into many smaller cells, each with its own nucleus.

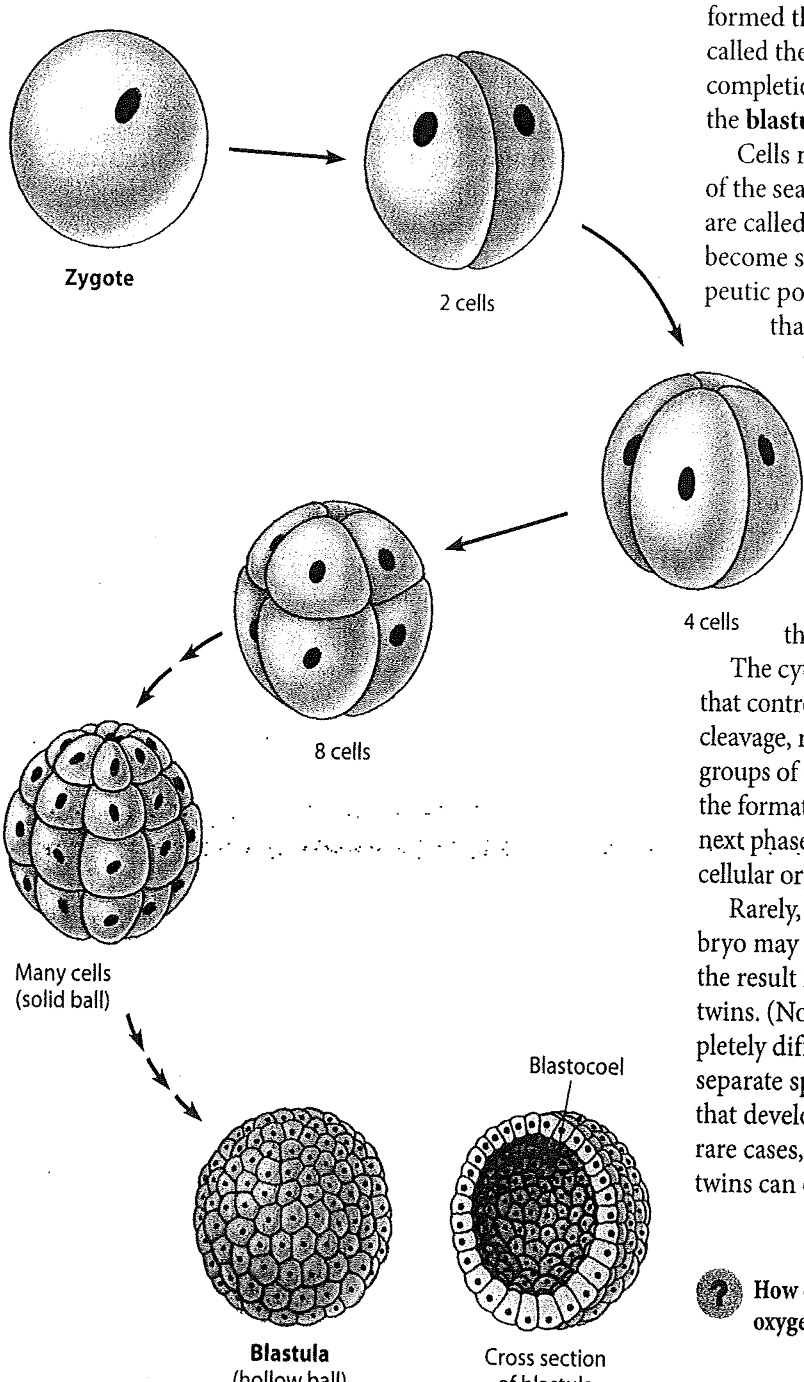
Figure 14.7 illustrates cleavage in a sea urchin. (A similar process occurs in humans.) As the first three steps show, the number of cells doubles with each cleavage division. In a sea urchin, a doubling occurs about every 20 minutes, and the whole cleavage process takes about 3 hours to produce a solid ball of cells. Notice that as cleavage proceeds, the total size of the ball remains constant even as the cells double. As a result, each cell in the ball is much smaller than the original cell that formed the zygote. As cleavage continues, a fluid-filled cavity called the **blastocoel** forms in the center of the embryo. At the completion of cleavage, there is a hollow ball of cells called the **blastula**.

Cells removed from a human blastocyst (the equivalent of the sea urchin blastula) are useful in research. Such cells are called embryonic stem cells. Because they have yet to become specialized, embryonic stem cells have great therapeutic potential to replace just about any kind of mature cells that have been lost to damage or illness. But harvesting the embryonic stem cells destroys the embryo, which raises ethical questions. Research using embryonic stem cells remains one of the hottest areas of biological study.

Cleavage makes two important contributions to early development. It creates a multicellular embryo, the blastula, from a single-celled zygote. Cleavage is also an organizing process, partitioning the multicellular embryo into developmental regions.

The cytoplasm of the zygote contains a variety of chemicals that control gene expression during early development. During cleavage, regulatory chemicals become localized in particular groups of cells, where they later activate the genes that direct the formation of specific parts of the animal. Gastrulation, the next phase of development, further refines the embryo's cellular organization.

Rarely, and apparently at random, a cell in the early embryo may separate and "reset" as if it were the original zygote; the result is the development of identical (monozygotic) twins. (Nonidentical, or dizygotic, twins result from a completely different mechanism: Two separate eggs fuse with two separate sperm to produce two genetically unique zygotes that develop in the uterus simultaneously.) In exceedingly rare cases, the separation and resetting that produce identical twins can occur twice, producing identical triplets.



▲ **Figure 14.7** Cleavage in a sea urchin

? How does the reduction of cell size during cleavage increase oxygen supply to the cells' mitochondria?

Smaller cells have a greater plasma membrane surface area relative to cellular volume, and this facilitates diffusion of oxygen from the environment to the cells' cytoplasm.

14.8 Gastrulation produces a three-layered embryo

After cleavage, the rate of cell division slows dramatically. Groups of cells then undergo **gastrulation**, the second major phase of embryonic development. During gastrulation, cells take up new locations that will allow later formation of all the organs and tissues. As gastrulation proceeds, the embryo is organized into a three-layer stage called a **gastrula**.

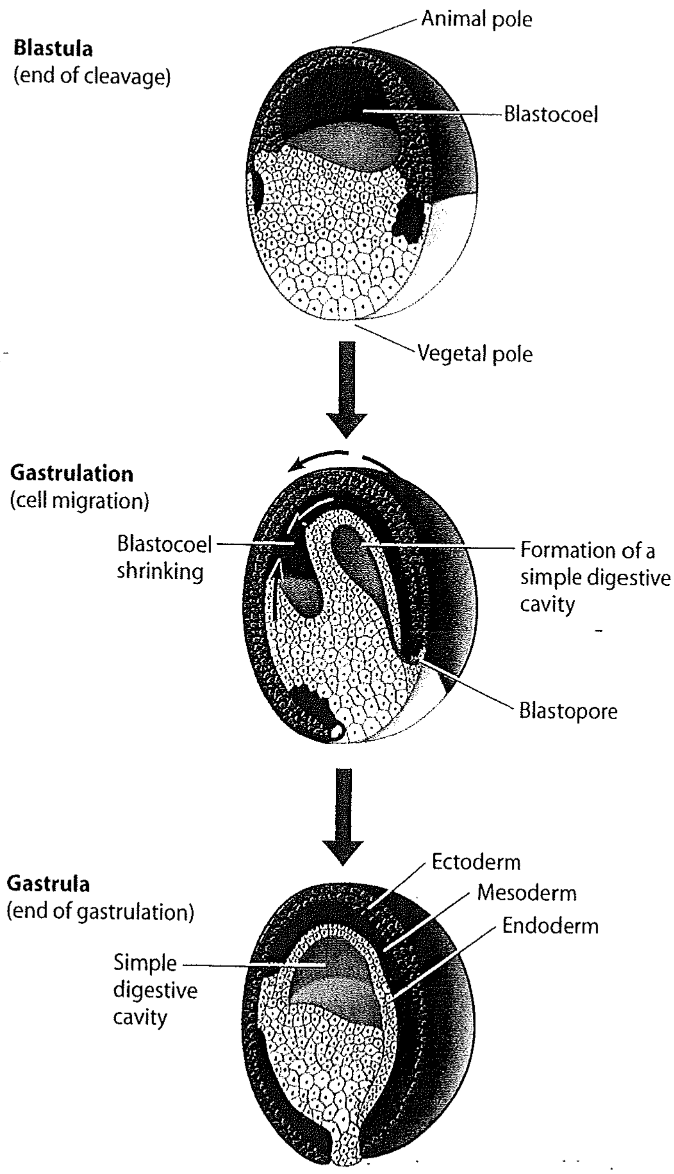
The three layers produced by gastrulation are embryonic tissues called **ectoderm**, **endoderm**, and **mesoderm**. The ectoderm forms the outer layer (skin) of the gastrula. The endoderm forms an embryonic digestive tract. And the mesoderm lies between the ectoderm and endoderm. Eventually, these three cell layers develop into all the parts of the adult animal. For instance, our nervous system and the outer layer (epidermis) of our skin come from ectoderm; the innermost lining of our digestive tract arises from endoderm; and most other organs and tissues, such as the kidney, heart, muscles, and the inner layer of our skin (dermis), develop from mesoderm. **Table 14.8** lists the major organs and tissues that arise in most vertebrates from the three main embryonic tissue layers.

The mechanics of gastrulation vary somewhat, depending on the species. We have chosen the frog, a vertebrate that has long been a favorite of researchers, to demonstrate how gastrulation produces three cell layers. The top of **Figure 14.8** shows the frog blastula, formed by cleavage (as discussed in the previous module). The frog blastula is a partially hollow ball of unequally sized cells. The cells toward one end, called the animal pole, are smaller than those near the opposite end, the vegetal pole. The three colors on the blastula in the figure indicate regions of cells that will give rise to the primary cell layers in the gastrula at the bottom of the figure: ectoderm (blue), endoderm (yellow), and mesoderm (red). (Notice that each layer may be more than one cell thick.)

During gastrulation (shown in the center of Figure 14.9), cells migrate to new positions that will form the three layers. Gastrulation begins when a small groove, called the blastopore, appears on one side of the blastula. In the blastopore, cells of the future endoderm (yellow) move inward from the surface and fold over to produce a simple digestive cavity. Meanwhile, the cells that will form ectoderm (blue) spread downward over more of the surface of the embryo, and the cells that will form mesoderm (red) begin to spread into a thin layer inside the embryo, forming a middle layer between the other two.

As shown at the bottom of the figure, gastrulation is completed when cell migration has resulted in a three-layered embryo. Ectoderm covers most of the surface. Mesoderm forms a layer between the ectoderm and the endoderm.

Although gastrulation differs in detail from one animal group to another, the process is driven by the same general mechanisms in all species. The timing of these events also varies with the species. In many frogs, for example, cleavage and gastrulation together take about 15–20 hours.



▲ **Figure 14.8** Development of the frog gastrula

TABLE 14.8 DERIVATIVES OF THE THREE EMBRYONIC TISSUE LAYERS

Embryonic Layer	Organs and Tissues in the Adult
Ectoderm	Epidermis of skin; epithelial lining of mouth and rectum; sense receptors in epidermis; cornea and lens of eye; nervous system
Endoderm	Epithelial lining of digestive tract (except mouth and rectum); epithelial lining of respiratory system; liver; pancreas; thyroid; parathyroids; thymus; lining of urethra, urinary bladder, and reproductive system
Mesoderm	Skeletal system; muscular system; circulatory system; excretory system; reproductive system (except gamete-forming cells); dermis of skin; lining of body cavity

? The first two phases of embryonic development are ______, which forms the blastula, followed by ______, which forms the ______.

cleavage . . . gastrulation . . . gastrula

CHAPTER 14 REVIEW

Reviewing the Concepts

Asexual and Sexual Reproduction (14.1–14.2)

14.1 Asexual reproduction results in the generation of genetically identical offspring. Asexual reproduction can proceed by budding, fission, or fragmentation/regeneration and enables one individual to produce many offspring rapidly.

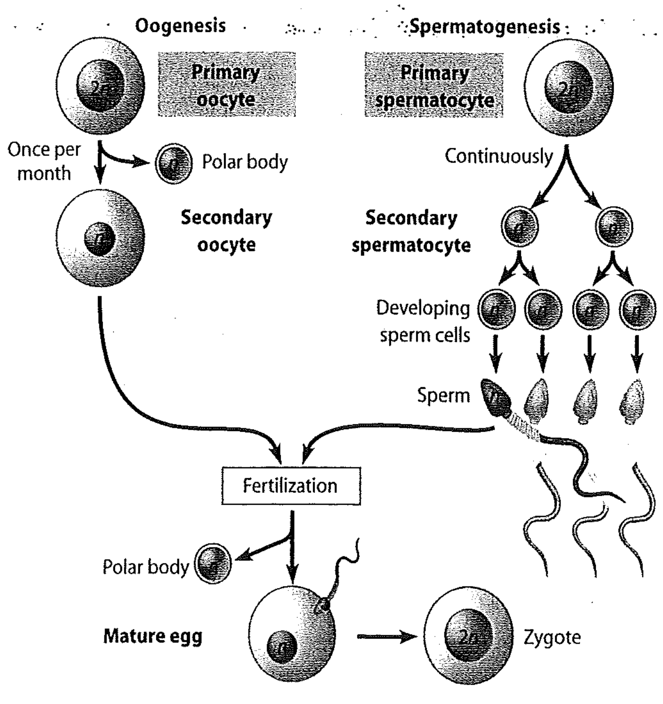
14.2 Sexual reproduction results in the generation of genetically unique offspring. Sexual reproduction involves the fusion of gametes from two parents, resulting in genetic variation among offspring. This may enhance survival of a population in a changing environment.

Human Reproduction (14.3–14.6)

14.3 Reproductive anatomy of the human female. The human reproductive system consists of a pair of ovaries (in females) or testes (in males), ducts that carry gametes, and structures for copulation. A woman's ovaries contain follicles that nurture eggs and produce sex hormones. Oviducts convey eggs to the uterus, where a fertilized egg develops. The uterus opens into the vagina, which receives the penis during intercourse and serves as the birth canal.

14.4 Reproductive anatomy of the human male. A man's testes produce sperm, which are expelled through ducts during ejaculation. Several glands contribute to the formation of fluid that nourishes and protects sperm.

14.5 The formation of sperm and egg cells requires meiosis. Spermatogenesis and oogenesis produce sperm and eggs, respectively. Primary spermatocytes are made continuously in the testes; these diploid cells undergo meiosis to form four haploid sperm. In females, each month, one primary oocyte forms a secondary oocyte, which, if penetrated by a sperm, completes meiosis and becomes a mature egg. The haploid nucleus of the mature egg then fuses with the haploid nucleus of the sperm, forming a diploid zygote.

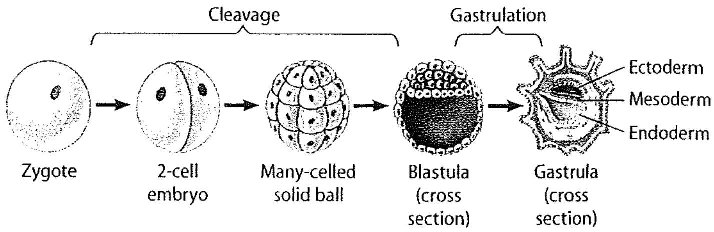


Principles of Embryonic Development (14.6–14.8)

14.6 Fertilization results in a zygote and triggers embryonic development. During fertilization, a sperm releases enzymes that pierce the egg's coat. Sperm surface proteins bind to egg receptor proteins, sperm and egg plasma membranes fuse, and the two nuclei unite. Changes in the egg membrane prevent entry of additional sperm, and the fertilized egg (zygote) develops into an embryo.

14.7 Cleavage produces a ball of cells from the zygote. Cleavage is a rapid series of cell divisions that results in a blastula.

14.8 Gastrulation produces a three-layered embryo. In gastrulation, cells migrate and form a rudimentary digestive cavity and three layers of cells.



Testing Your Knowledge

Multiple Choice

1. After a sperm penetrates an egg, it is important that the vitelline layer separate from the egg so that it can
   a. secrete important hormones.
   b. enable the fertilized egg to implant in the uterus.
   c. prevent more than one sperm from entering the egg.
   d. attract additional sperm to the egg.
   e. activate the egg for embryonic development.
2. In an experiment, a researcher colored a bit of tissue on the outside of a frog gastrula with an orange fluorescent dye. The embryo developed normally. When the tadpole was placed under an ultraviolet light, which of the following glowed bright orange? (*Explain your answer.*)
   a. the heart
   b. the pancreas
   c. the brain
   d. the stomach
   e. the liver
3. How does a zygote differ from a mature egg?
   a. A zygote has more chromosomes.
   b. A zygote is smaller.
   c. A zygote consists of more than one cell.
   d. A zygote is much larger.
   e. A zygote divides by meiosis.

Matching

4. Turns into the corpus luteum	a. vas deferens
5. Female gonad	b. prostate gland
6. Site of spermatogenesis	c. endometrium
7. Site of fertilization in humans	d. testis
8. Site of human gestation	e. follicle
9. Sperm duct	f. uterus
10. Secretes seminal fluid	g. ovary
11. Lining of uterus	h. oviduct

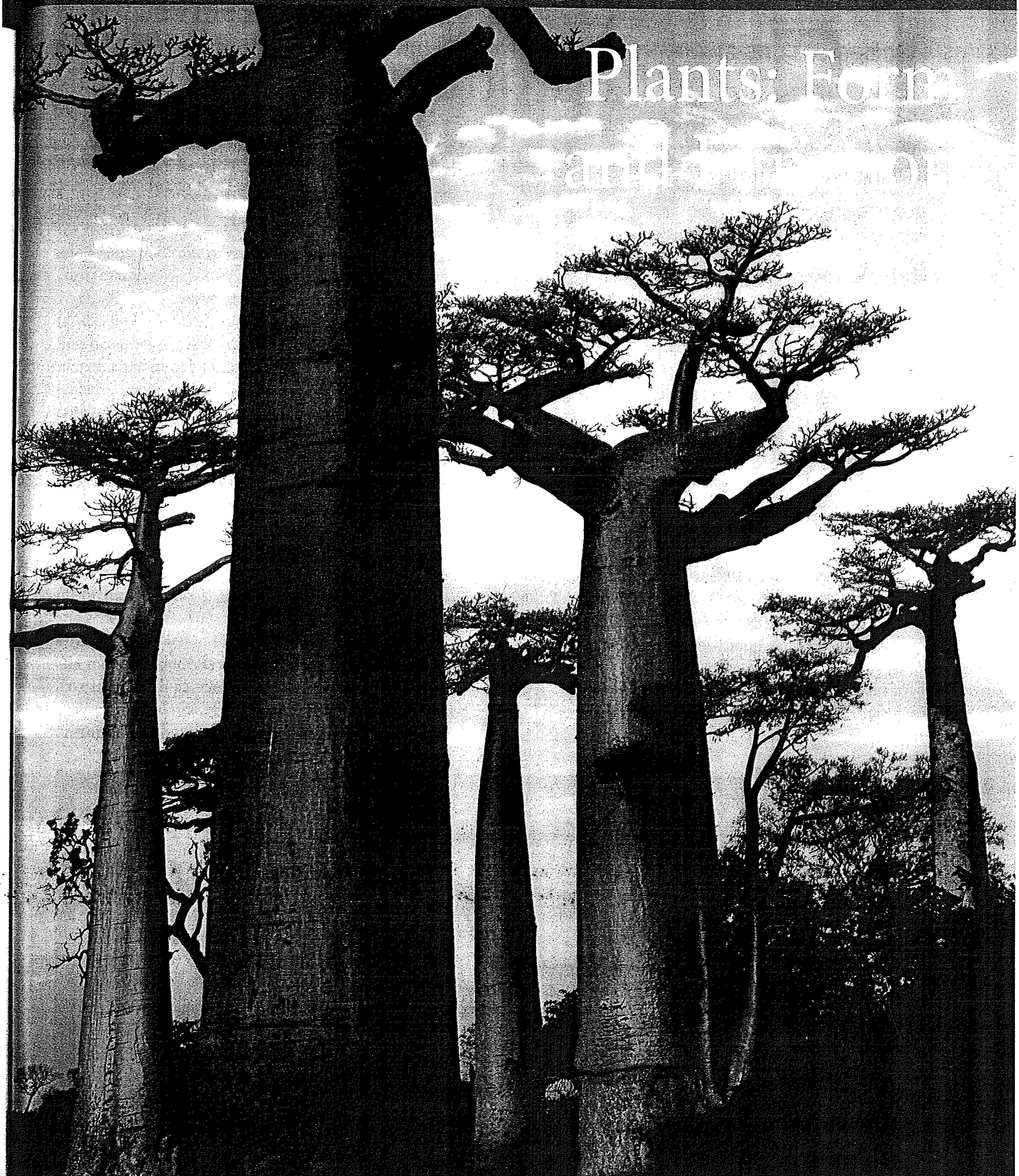
Describing, Comparing, and Explaining

12. Compare sperm formation with egg formation. In what ways are the processes similar? In what ways are they different?

Answers to all questions can be found in Appendix 1.

UNIT IV

Plants: Form and Function

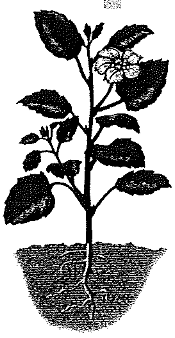


CHAPTER

15

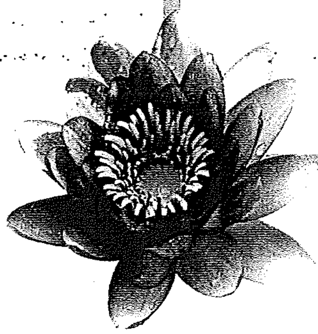
Plant Structure and Reproduction

BIG IDEAS



Plant Structure and Function
(15.1–15.4)

Plant bodies contain specialized cells grouped into tissues, organs, and organ systems.



Reproduction of Flowering Plants
(15.5–15.9)

Sexual reproduction in angiosperms involves pollination, development of fruit and seeds, seed dispersal, germination, and growth.

Plant Structure and Function

15.1 The two major groups of angiosperms are the monocots and the eudicots

Angiosperms have dominated the land for over 100 million years, and there are about 250,000 known species of flowering plants living today. Most of our foods come from a few hundred domesticated species of flowering plants. Among these foods are roots, such as beets and carrots; the fruits of trees and vines, such as apples, nuts, berries, and squashes; the fruits and seeds of legumes, such as peas and beans; and grains, the fruits of grasses such as wheat, rice, and corn (maize).

On the basis of several structural features, plant biologists (also called botanists) traditionally placed most angiosperms into two groups, called monocots and dicots. The names *monocot* and *dicot* refer to the first leaves on the plant embryo. These embryonic leaves are called seed leaves, or **cotyledons**. A **monocot** embryo has one seed leaf; a **dicot** embryo has two seed leaves. The great majority of dicots, called the **eudicots** ("true" dicots), are related, having diverged from a common ancestor about 125 million years ago; a few smaller groups of dicots have developed independently. In this chapter, we will focus on monocots and eudicots **(Figure 15.1)**.

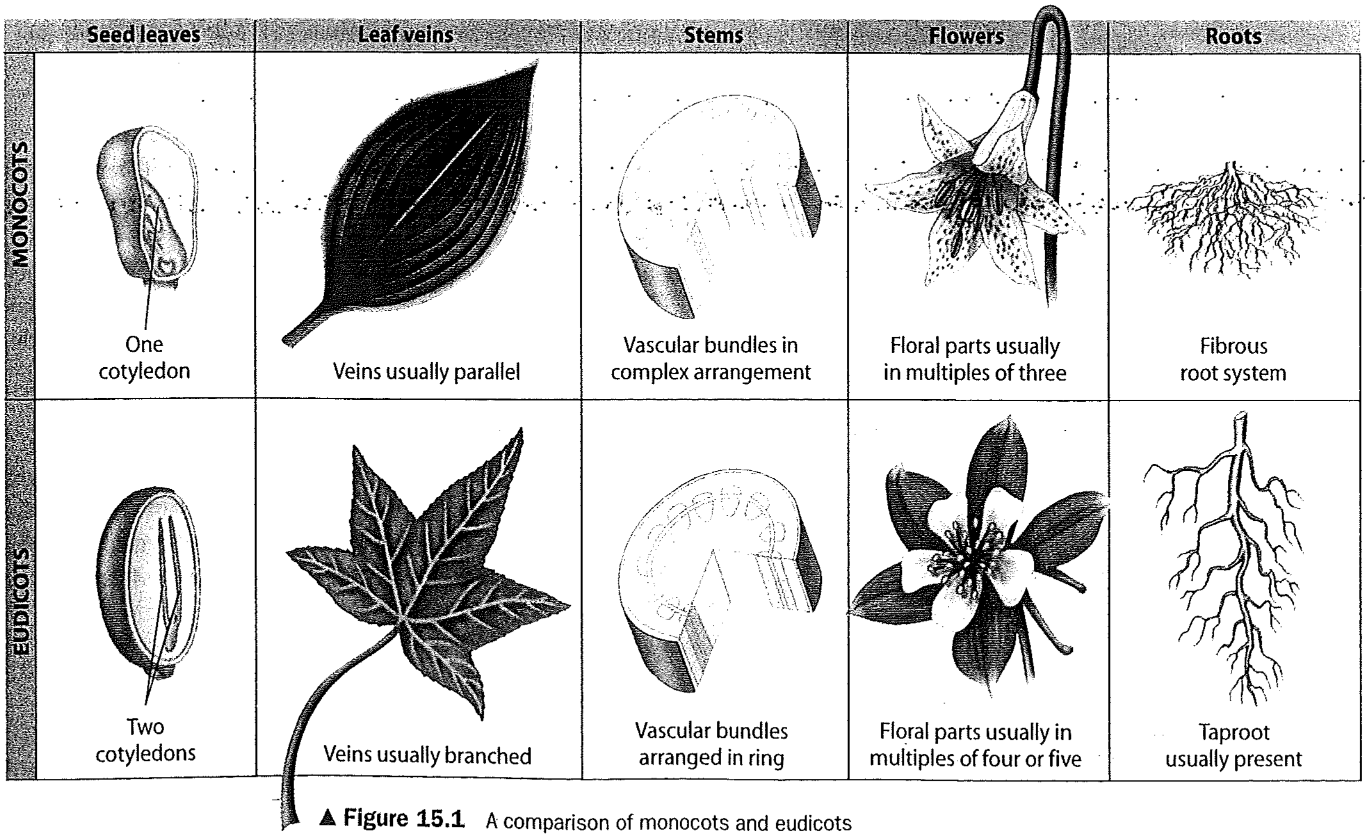
Monocots are a large group of related plants that include the orchids, bamboos, palms, and lilies, as well as the grains and other grasses. You can see the single cotyledon inside the seed on the top left in Figure 15.1. The leaves, stems, flowers, and roots of monocots are also distinctive. Most monocots have leaves with parallel veins. Monocot stems have vascular tissues (internal tissues that transport water and nutrients) organized into bundles that are arranged in a scattered pattern. The flowers of most monocots have their petals and other parts in multiples of three. Monocot roots form a shallow fibrous system—a mat of threads—that spreads out below the soil surface. With most of their roots in the top few centimeters of soil, monocots, especially grasses, make excellent ground cover that reduces erosion. Fibrous root systems are well adapted to shallow soils where rainfall is light.

Most flowering shrubs and trees are eudicots, such as the majority of our ornamental plants and many of our food crops, including nearly all of our fruits and vegetables. You can see the two cotyledons of a typical eudicot in the seed on the lower left in Figure 15.1. Eudicot leaves have a multi-branched network of veins, and eudicot stems have vascular bundles arranged in a ring. Eudicot flowers usually have petals and other parts in multiples of four or five. The large, vertical root of a eudicot, which is known as a taproot, goes deep into the soil, as you know if you've ever tried to pull up a dandelion. Taproots are well adapted to soils with deep groundwater.

As we saw in the preceding unit on animals, a close look at a structure often reveals its function. Conversely, function provides insight into the "logic" of a structure. In the modules that follow, we'll take a detailed look at the correlation between plant structure and function.

? **The terms *monocot* and *eudicot* refer to the number of ______ on the developing embryo in a seed.**

cotyledons (seed leaves)



▲ **Figure 15.1** A comparison of monocots and eudicots

15.2 A typical plant body contains three basic organs: roots, stems, and leaves

Plants, like most animals, have organs composed of different tissues, which in turn are composed of one or more cell types. An **organ** consists of several types of tissues that together carry out particular functions. In this module we'll focus on plant organs. We will then work our way down the structural hierarchy and examine plant tissues (in Module 15.3) and cells (in Module 15.4).

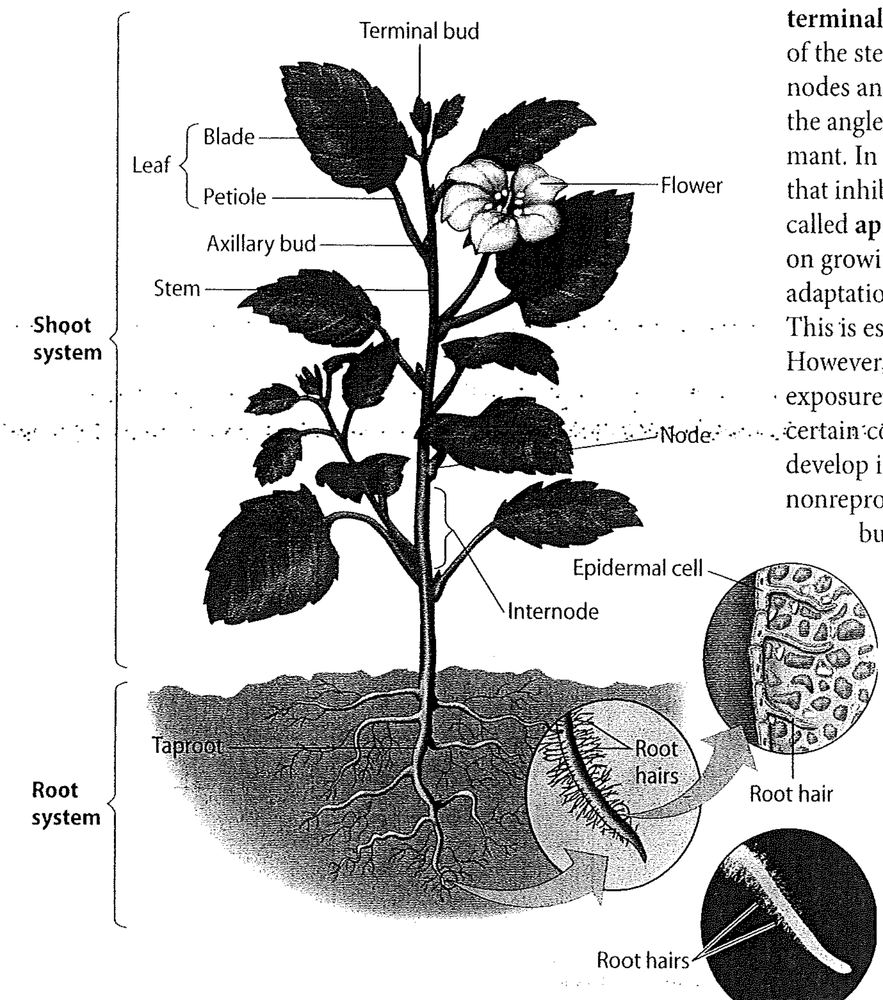
The basic structure of plants reflects their developmental history as land-dwelling organisms. Most plants must draw resources from two very different environments: They must absorb water and minerals from the soil, while simultaneously obtaining CO_2 and light from above ground. The subterranean roots and aerial shoots (stems and leaves) of a typical land plant, such as the generalized flowering plant shown in **Figure 15.2**, perform these vital functions. Neither roots nor shoots can survive without the other. Lacking chloroplasts and living in the dark, most roots would starve without sugar and other organic nutrients transported from the photosynthetic leaves of the shoot system. Conversely, stems and leaves depend on the water and minerals absorbed by roots.

A plant's **root system** anchors it in the soil, absorbs and transports minerals and water, and stores food. Near the root tips, a vast number of tiny tubular projections called **root hairs** enormously increase the root surface area for absorption of water and minerals. As shown on the far right of the figure, each root hair is an extension of an epidermal cell (a cell in the outer layer of the root). It is difficult to move an established plant without injuring it because transplantation often damages the plant's delicate root hairs.

The **shoot system** of a plant is made up of stems, leaves, and adaptations for reproduction, which in angiosperms are the flowers. (We'll return to flowers in Module 15.5.) The **stems** are the parts of the plant that are generally above the ground and that support and separate the leaves (thereby promoting photosynthesis) and flowers (responsible for reproduction). In the case of a tree, the stems are the trunk and all the branches, including the smallest twigs. A stem has **nodes**, the points at which leaves are attached, and **internodes**, the portions of the stem between nodes. The **leaves** are the main photosynthetic organs in most plants, although green stems also perform photosynthesis. Most leaves consist of a flattened blade and a stalk, or petiole, which joins the leaf to a node of the stem.

The two types of buds in the figure are undeveloped shoots. When a plant stem is growing in length, the **terminal bud** (also called the apical bud), at the apex (tip) of the stem has developing leaves and a compact series of nodes and internodes. The **axillary buds**, one in each of the angles formed by a leaf and the stem, are usually dormant. In many plants, the terminal bud produces hormones that inhibit growth of the axillary buds, a phenomenon called **apical dominance**. By concentrating resources on growing taller, apical dominance is a developmental adaptation that increases the plant's exposure to light. This is especially important where vegetation is dense. However, branching is also important for increasing the exposure of the shoot system to the environment, and under certain conditions, the axillary buds begin growing. Some develop into shoots bearing flowers, and others become nonreproductive branches complete with their own terminal buds, leaves, and axillary buds. Removing the terminal bud usually stimulates the growth of axillary buds. This is why pruning fruit trees and "pinching back" houseplants makes them bushier.

The drawing in Figure 15.2 gives an overview of plant structure, but it by no means represents the enormous diversity of angiosperms. Next, let's look briefly at some variations on the basic themes of root and stem structure.



▲ Figure 15.2 The body plan of a flowering plant (a eudicot)

? Name the two organ systems and three basic organs found in typical plants.

Root system and shoot system; roots, stems, leaves.

15.3 Three tissue systems make up the plant body

Like the organs of most animals, the organs of plants contain tissues with characteristic functions. A **tissue** is a group of cells that together perform a specialized function. For example, **xylem** tissue contains water-conducting cells that convey water and dissolved minerals upward from the roots, while **phloem** tissue contains cells that transport sugars and other organic nutrients from leaves or storage tissues to other parts of the plant.

Each plant organ—root, stem, or leaf—has three types of tissues: dermal, vascular, and ground tissues. Each of these three categories forms a **tissue system**, a functional unit connecting all of the plant's organs. Each tissue system is continuous throughout the entire plant body, but the systems are arranged differently in leaves, stems, and roots **(Figure 15.3)**. In this module, we examine the tissue systems of young roots and shoots. Later we will see that the tissue systems are somewhat different in older roots and stems.

The **dermal tissue system** (brown in the figure) is the plant's outer protective covering. Like our own skin, it forms the first line of defense against physical damage and infectious organisms. In many plants, the dermal tissue system consists of a single layer of tightly packed cells called the **epidermis**. The epidermis of leaves and most stems has a waxy coating called the **cuticle**, which helps prevent water loss. The second tissue system is the **vascular tissue system** (purple). It is made up of xylem and phloem tissues and provides support and long-distance transport between the root and shoot systems. Tissues that are neither dermal nor vascular make up the **ground tissue system** (yellow). It accounts for most of the bulk of a young plant, filling the spaces between the epidermis and vascular tissue system. Ground tissue internal to the vascular tissue is called **pith**, and ground tissue external to the vascular tissue is called **cortex**. The ground tissue system has diverse functions, including photosynthesis, storage, and support.

The close-up views on the right side of Figure 15.3 show how these three tissue systems are organized in typical plant roots, stems, and leaves. The view at the bottom left shows in cross section the three tissue systems in a young eudicot root. Water and minerals that are absorbed from the soil must enter through the epidermis. In the center of the root, the vascular tissue system forms a **vascular cylinder**, with the cross sections of xylem cells radiating from the center like spokes of a wheel and phloem cells filling in the wedges between the spokes. The ground tissue system of the root, the region between the vascular cylinder and epidermis, consists entirely of cortex. The cortex cells store food as starch and take up minerals that have entered the root through the epidermis. The innermost layer of the cortex is the **endodermis**, a cylinder one cell thick. The endodermis is a selective barrier, determining which substances pass between the rest of the cortex and the vascular tissue (as you'll see in Module 16.2).

The bottom right of Figure 15.3 shows a cross section of a young monocot root. There are several similarities to the eudicot root: an outer layer of epidermis (dermal tissue) surrounding a large cortex (ground tissue), with a vascular cylinder (vascular tissue) at the center. But in a monocot root, the vascular tissue consists of a central core of cells surrounded by a ring of xylem and a ring of phloem.

As the center of Figure 15.3 indicates, the young stem of a eudicot looks quite different from that of a monocot. Both stems have their vascular tissue system arranged in numerous **vascular bundles**. However, in monocot stems the bundles are scattered, whereas in eudicots they are arranged in a ring. This ring separates the ground tissue into cortex and pith regions. The cortex fills the space between the vascular ring and the epidermis. The pith fills the center of the stem and is often important in food storage. In a monocot stem, the ground tissue is not separated into these regions because the vascular bundles don't form a ring.

The top of Figure 15.3 illustrates the arrangement of the three tissue systems in a typical eudicot leaf. The epidermis is interrupted by tiny pores called **stomata** (singular, *stoma*), which allow exchange of CO_2 and O_2 between the surrounding air and the photosynthetic cells inside the leaf. Also, most of the water vapor lost by a plant passes through stomata. Each stoma is flanked by two **guard cells**, which regulate the opening and closing of the stoma.

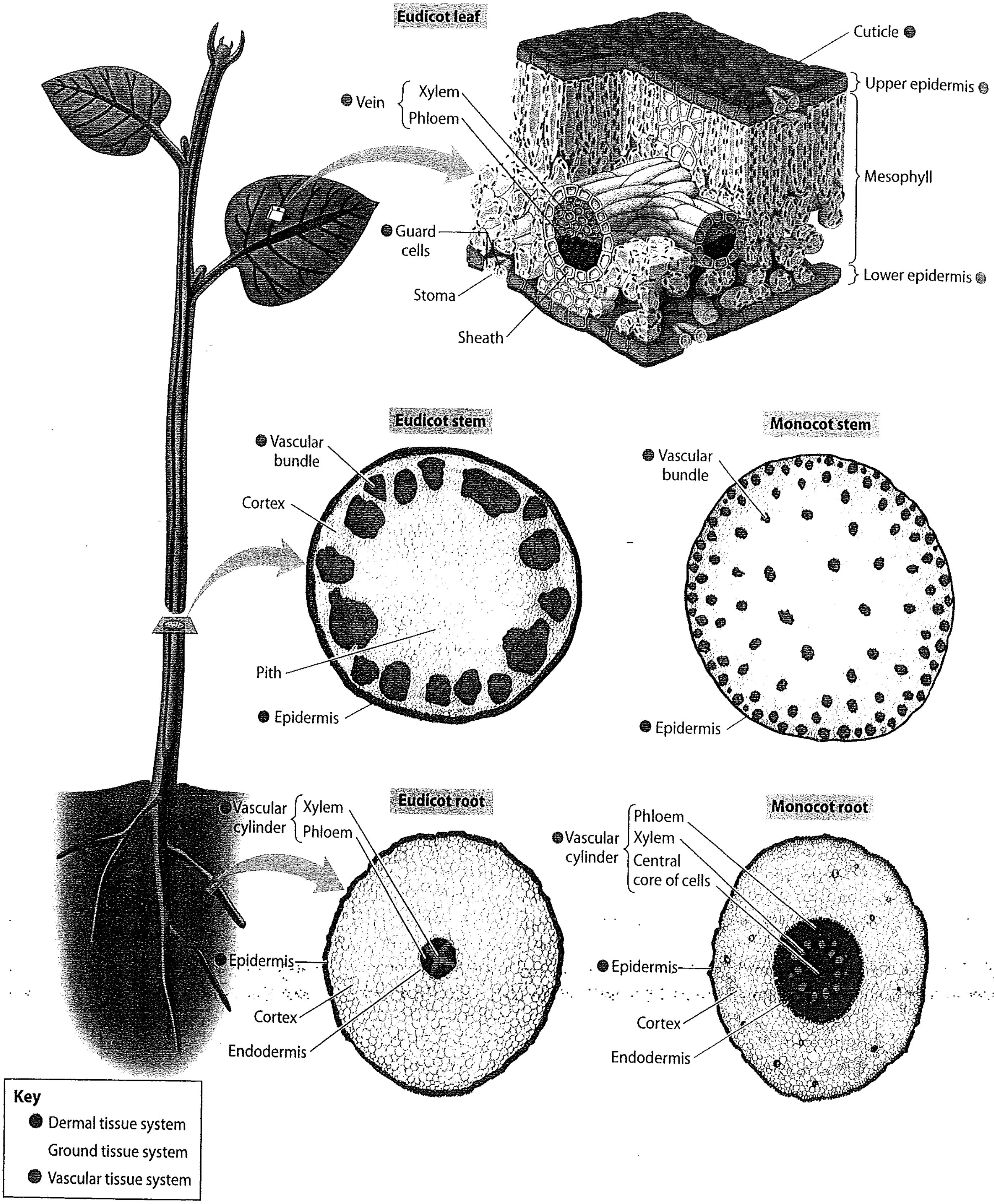
The ground tissue system of a leaf, called the **mesophyll**, is sandwiched between the upper and lower epidermis. Mesophyll consists mainly of cells specialized for photosynthesis. The green structures in the diagram are their chloroplasts. In this eudicot leaf, notice that cells in the lower area of mesophyll are loosely arranged, with a labyrinth of air spaces through which CO_2 and O_2 circulate. The air spaces are particularly large in the vicinity of stomata, where gas exchange with the outside air occurs. In many monocot leaves and in some eudicot leaves, the mesophyll is not arranged in distinct upper and lower areas.

In both monocots and eudicots, the leaf's vascular tissue system is made up of a network of veins. As you can see in Figure 15.3, each **vein** is a vascular bundle composed of xylem and phloem tissues surrounded by a protective sheath of cells. The veins' xylem and phloem, continuous with the vascular bundles of the stem, are in close contact with the leaf's photosynthetic tissues. This ensures that those tissues are supplied with water and mineral nutrients from the soil and that sugars made in the leaves are transported throughout the plant. The vascular structure also functions as a skeleton that reinforces the shape of the leaf.

In the previous modules, we have examined plant structure at the level of organs and tissues. In the next module, we will complete our descent into the structural hierarchy of plants by taking a look at plant cells.

? For each of the following structures in your body, name the most analogous plant tissue system: circulatory system, skin, adipose tissue (body fat).

Vascular tissue system, dermal tissue system, ground tissue system.



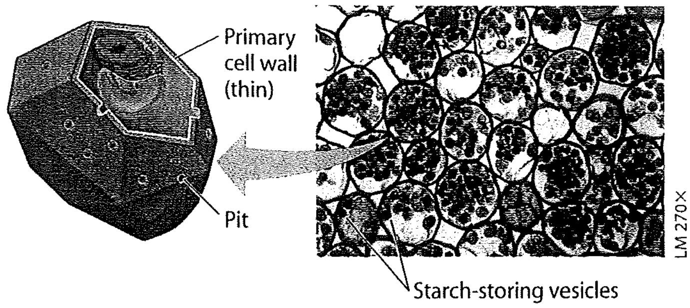
▲ **Figure 15.3** The three tissue systems

15.4 Plant cells are diverse in structure and function

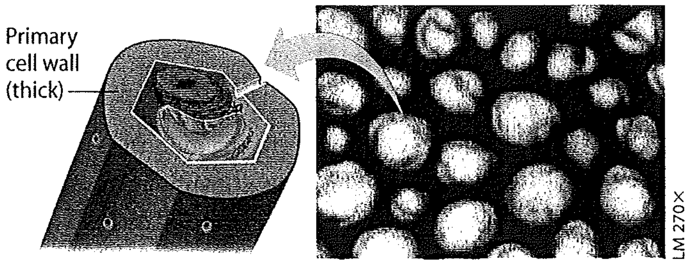
In addition to features shared with other eukaryotic cells (see Module 3.3), most plant cells have three unique structures (**Figure 15.4A**): chloroplasts, the sites of photosynthesis; a central vacuole containing fluid that helps maintain cell turgor (firmness); and a protective cell wall made from the structural carbohydrate cellulose surrounding the plasma membrane.

The enlargement on the right in Figure 15.4A highlights the adjoining cell walls of two cells. Many plant cells, especially those that provide structural support, have a two-part cell wall; a primary cell wall is laid down first, and then a more rigid secondary cell wall forms between the plasma membrane and the primary wall. The primary walls of adjacent cells in plant tissues are held together by a sticky layer called the middle lamella. Pits, where the cell wall is relatively thin, allow migration of water between adjacent cells. Plasmodesmata are open channels in adjacent cell walls through which cytoplasm and various molecules can flow from cell to cell.

The structure of a plant cell and the nature of its wall often correlate with the cell's main functions. As you consider the five major types of plant cells shown in Figures 15.4B–15.4F, notice the structural adaptations that make their specific functions possible.



▲ **Figure 15.4B** Parenchyma cell



▲ **Figure 15.4C** Collenchyma cell

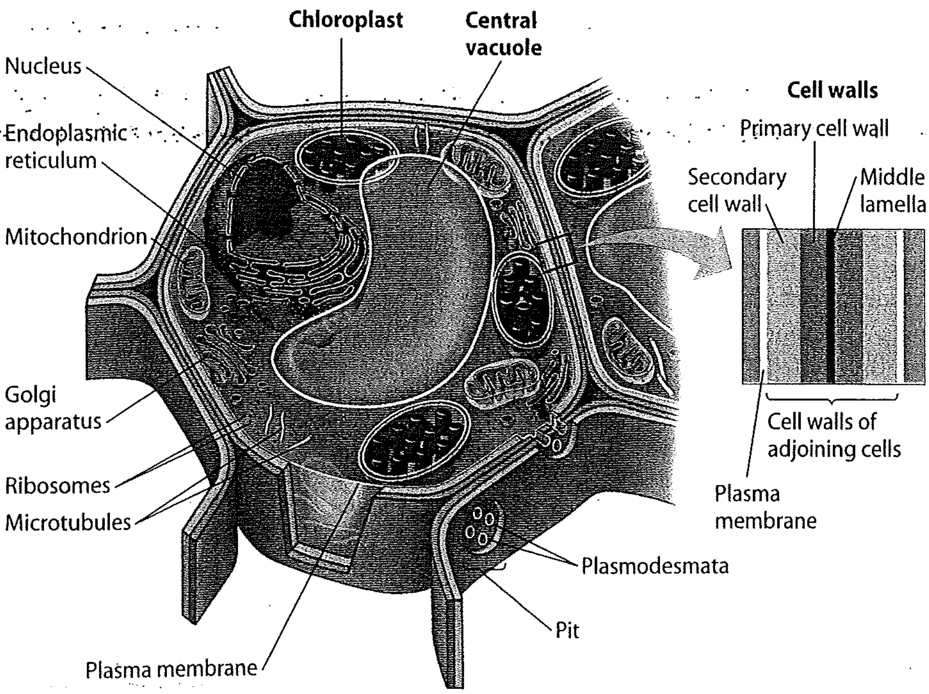
Parenchyma cells (Figure 15.4B) are the most abundant type of cell in most plants. They usually have only primary cell walls, which are thin and flexible. Parenchyma cells perform most metabolic functions of a plant, such as photosynthesis, aerobic respiration, and food storage. Most parenchyma cells can divide and differentiate into other types of plant cells under certain conditions, such as during the repair of an injury. In the laboratory, it is even possible to regenerate an entire plant from a single parenchyma cell.

Collenchyma cells (Figure 15.4C) resemble parenchyma cells in lacking secondary walls, but they have unevenly thickened primary walls. These cells provide flexible support in actively growing parts of the plant; young stems and petioles often have collenchyma cells just below their surface (the "string" of a celery stalk, for example). These living cells elongate as stems and leaves grow.

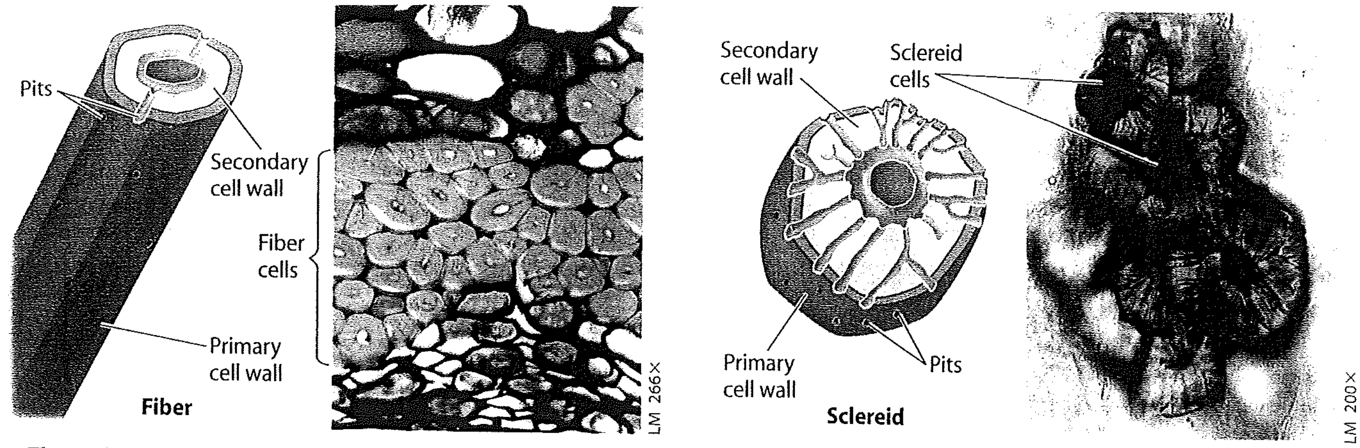
Sclerenchyma cells (Figure 15.4D) have thick secondary cell walls usually strengthened with lignin, the main chemical component of wood. Mature sclerenchyma cells cannot elongate and thus are found only in regions of the plant that have stopped growing in length. When mature, most sclerenchyma cells are dead, their cell walls forming a rigid "skeleton" that supports the plant much as steel beams do in the interior of a building.

Figure 15.4D shows two types of sclerenchyma cells. One, called a **fiber**, is long and slender and is usually arranged in bundles. Some plant tissues with abundant fiber cells are commercially important; hemp fibers, for example, are used to make rope and clothing. **Sclereids**, which are shorter than fiber cells, have thick, irregular, and very hard secondary walls. Sclereids impart the hardness to nutshells and seed coats and the gritty texture to the soft tissue of a pear.

The xylem tissue of angiosperms includes two types of water-conducting cells: tracheids and vessel elements. Both have rigid, lignin-containing secondary cell walls. As **Figure 15.4E** shows, the **tracheids** are long, thin cells with tapered ends. **Vessel**



▲ **Figure 15.4A** The structure of a plant cell



▲ **Figure 15.4D** Sclerenchyma cells: fiber (left) and sclereid (right)

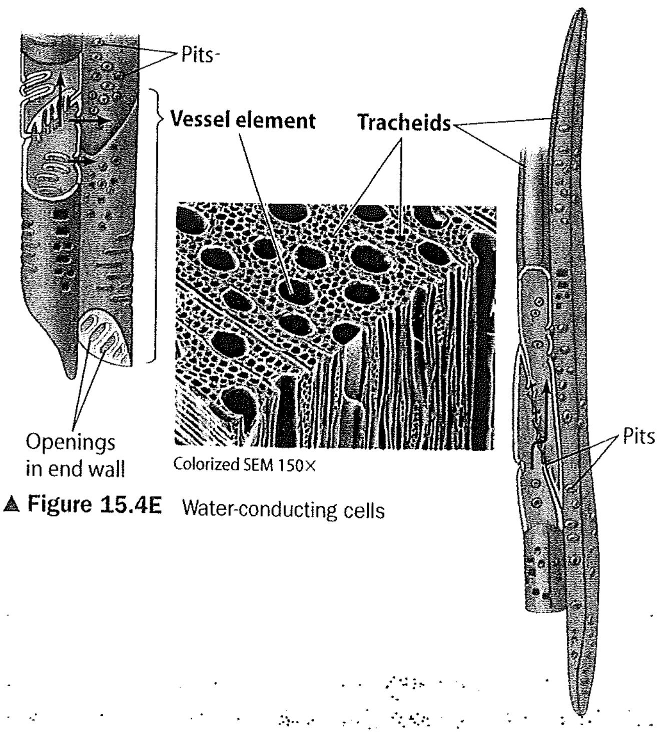
elements are wider, shorter, and less tapered. Chains of tracheids or vessel elements with overlapping ends form a system of tubes that conveys water from the roots to the stems and leaves as part of xylem tissue. The tubes are hollow because both tracheids and vessel elements are dead when mature, with only their cell walls remaining. Water passes through pits in the walls of tracheids and vessel elements and through openings in the end walls of vessel elements. With their thick, rigid walls, these cells also function in support.

Food-conducting cells, known as **sieve-tube elements** (or sieve-tube members), are also arranged end to end, forming tubes as part of phloem tissue **(Figure 15.4F)**. Unlike water-conducting cells, however, sieve-tube elements remain alive at maturity, though they lose most organelles, including the nucleus and ribosomes. This reduction in cell contents enables nutrients to pass more easily through the cell. The end walls between sieve-tube elements, called **sieve plates**, have pores that allow fluid to flow from cell to cell along the sieve tube. Alongside each sieve-tube element is at least one **companion cell**, which is connected to the sieve-tube element by numerous plasmodesmata. One companion cell may serve multiple sieve-tube elements by producing and transporting proteins to all of them.

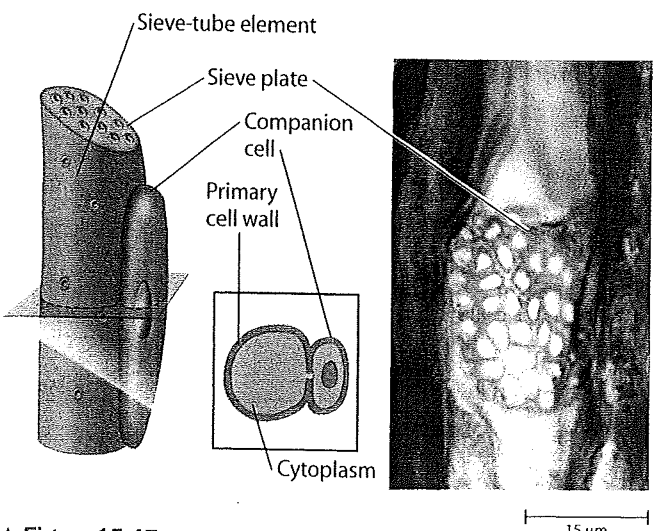
Now that we have reached the lowest level in the structural hierarchy of plants—cells—let's review by moving back up. Cells of plants are grouped into tissues with characteristic functions. For example, xylem tissue contains water-conducting cells that convey water and dissolved minerals upward from the roots as well as sclerenchyma cells, which provide support, and parenchyma cells, which store various materials. Xylem and phloem tissues are organized into the vascular tissue system, which provides structural support and long-term transport throughout the plant body. The vascular, dermal, and ground tissue systems connect all the plant organs: roots, stems, and leaves. This review completes our survey of basic plant anatomy. Next, we examine how plants grow.

? **Identify which of the following cell types can give rise to all others in the list: collenchyma, sclereid, parenchyma, vessel element, companion cell.**

Parenchyma.



▲ **Figure 15.4E** Water-conducting cells

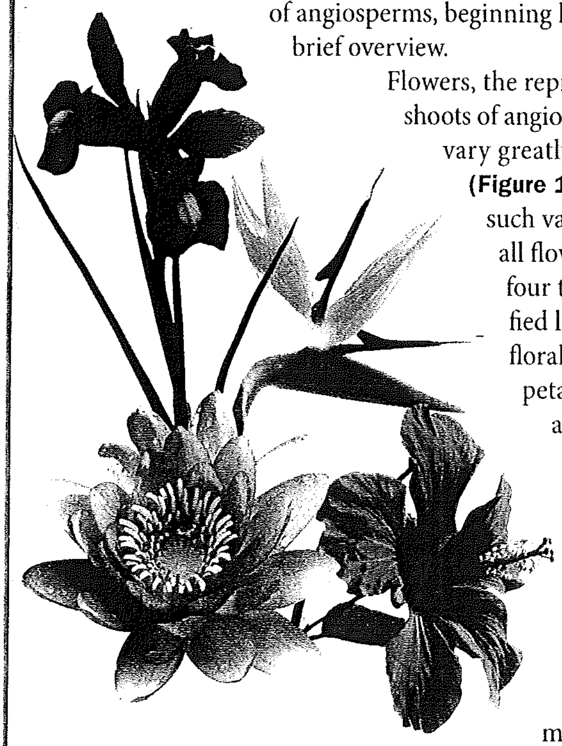


▲ **Figure 15.4F** Food-conducting cell (sieve-tube element)

Reproduction of Flowering Plants

15.5 The flower is the organ of sexual reproduction in angiosperms

It has been said that an oak tree is merely an acorn's way of making more acorns. Indeed, developmental fitness for any organism is measured only by its ability to produce healthy, fertile offspring. Thus, from an developmental viewpoint, all the structures and functions of a plant can be interpreted as mechanisms contributing to reproduction. In the remaining modules, we explore the reproductive biology of angiosperms, beginning here with a brief overview.



▲ **Figure 15.5A**
Some variations in flower shape

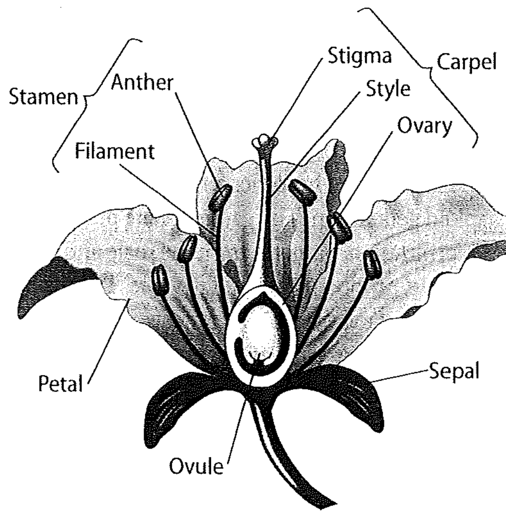
Flowers, the reproductive shoots of angiosperms, can vary greatly in shape (**Figure 15.5A**). Despite such variation, nearly all flowers contain four types of modified leaves called floral organs: sepals, petals, stamens, and carpels (**Figure 15.5B**). The **sepals**, which enclose and protect the flower bud, are usually green and more leaflike than the other floral organs (picture the green at the base of a rosebud). The **petals** are often colorful and advertise the flower to pollinators. The stamens and carpels are the reproductive organs, containing the sperm and eggs, respectively.

A **stamen** consists of a stalk (filament) tipped by an anther. Within the **anther** are sacs in which pollen is produced via meiosis. Pollen grains house the cells that develop into sperm.

A **carpel** has a long slender neck (style) with a sticky stigma at its tip. The **stigma** is the landing platform for pollen. The base of the carpel is the **ovary**, which contains one or more **ovules**, each containing a developing egg and supporting cells. The term **pistil** is sometimes used to refer to a single carpel or a group of fused carpels.

Figure 15.5C shows the life cycle of a generalized angiosperm. ① Fertilization occurs in an ovule within a flower. ② As the ovary develops into a fruit, ③ the ovule develops into the seed containing the embryo. The fruit protects the seed and aids in dispersing it. Completing the life cycle, ④ the seed then **germinates** (begins to grow) in a suitable habitat; ⑤ the embryo develops into a seedling; and the seedling grows into a mature plant.

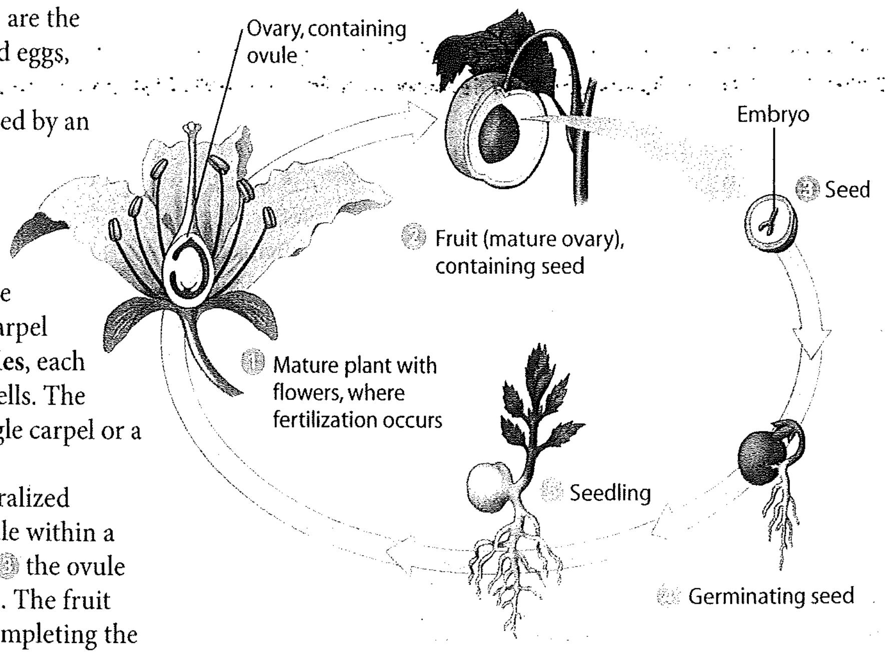
In the next four modules, we examine key stages in the angiosperm sexual life cycle in more detail. We will see that there are a number of variations in the basic themes presented here.



▲ **Figure 15.5B** The structure of a flower

? Pollen develops within the ______ of ______. Ovules develop within the ______ of ______.

anthers . . . stamens . . . ovaries . . . carpels



▲ **Figure 15.5C** Life cycle of a generalized angiosperm

15.6 The development of pollen and ovules culminates in fertilization

The life cycles of plants are characterized by an alternation of generations, in which haploid (n) and diploid ($2n$) generations take turns producing each other. The roots, stems, leaves, and most of the reproductive structures of angiosperms are diploid. The diploid plant body is called the **sporophyte**. A sporophyte produces special structures, the anthers and ovules, in which cells undergo meiosis to produce haploid cells called spores. Each spore then divides via mitosis and becomes a multicellular **gametophyte**, the plant's haploid generation. The gametophyte produces gametes by mitosis. At fertilization, gametes from the male and female gametophytes unite, producing a diploid zygote. The life cycle is completed when the zygote divides by mitosis and develops into a new sporophyte. In angiosperms, the sporophyte is the dominant generation: It is larger, more obvious, and longer-living than the gametophyte. In this module, we take a microscopic look at the gametophytes of a flowering plant.

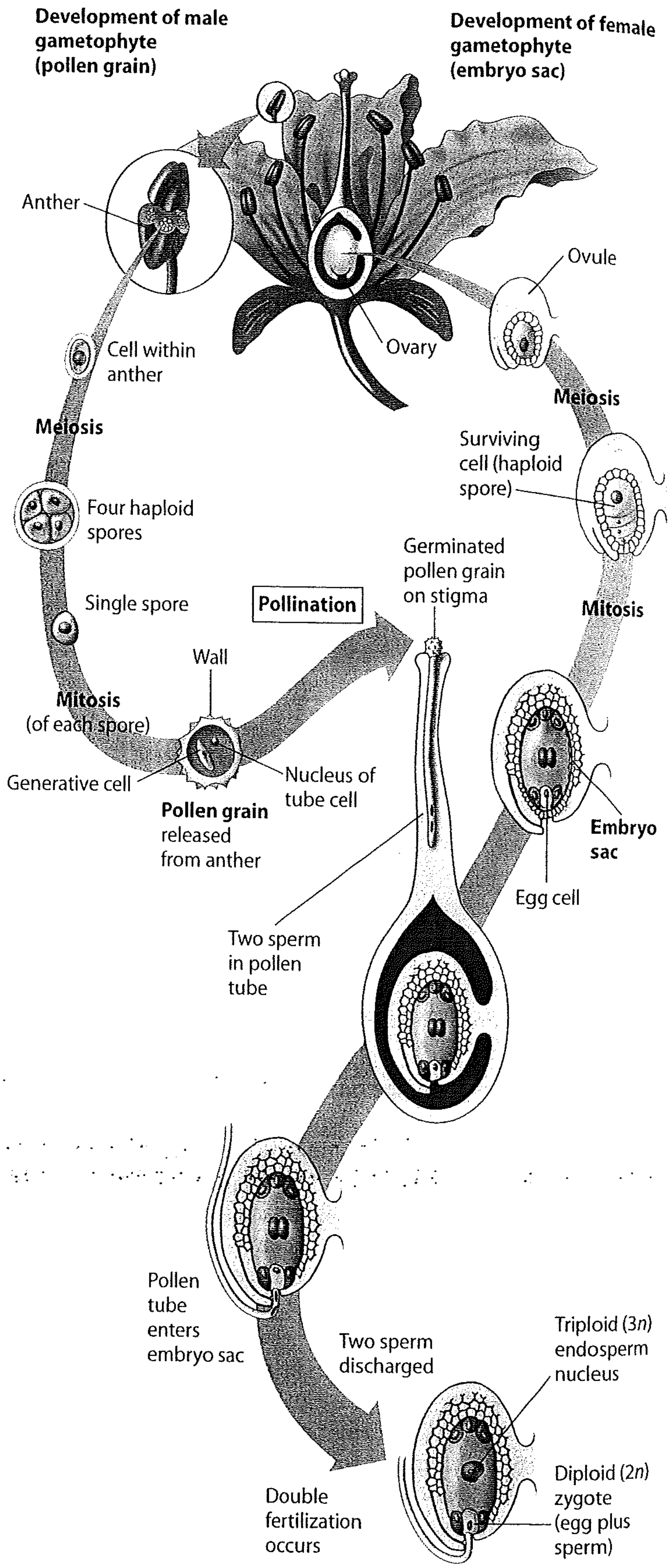
Pollen grains are the male gametophytes. The cells that develop into pollen grains are found within a flower's anthers (top left in **Figure 15.6**). Each cell first undergoes meiosis, forming four haploid spores. Each spore then divides by mitosis, forming two haploid cells, called the tube cell and the generative cell. The generative cell passes into the tube cell, and a thick wall forms around them. The resulting pollen grain is ready for release from the anther.

Moving to the top right of the figure, we can follow the development of the flower parts that form the female gametophyte and eventually the egg. In most species, the ovary of a flower contains several ovules, but only one is shown here. An ovule contains a central cell (gold) surrounded by a protective covering of smaller cells (yellow). The central cell enlarges and undergoes meiosis, producing four haploid spores. Three of the spores usually degenerate, but the surviving one enlarges and divides by mitosis, producing a multicellular structure known as the **embryo sac**. Housed in several layers of protective cells (yellow) produced by the sporophyte plant, the embryo sac is the female gametophyte. The sac contains a large central cell with two haploid nuclei. One of its other cells is the haploid egg, ready to be fertilized.

The first step leading to fertilization is **pollination** (at the center of the figure), the delivery of pollen from anther to stigma. Most angiosperms depend on insects, birds, or other animals to transfer pollen. Most major crops rely on insects, mainly bees. But the pollen of some plants—such as grasses and many trees—is windborne (as anyone bothered by pollen allergies knows).

After pollination, the pollen grain germinates on the stigma. Its tube cell gives rise to the pollen tube, which grows downward into the ovary. Meanwhile, the generative cell divides by mitosis, forming two sperm. When the pollen tube reaches the base of the ovule, it enters the ovary and discharges its two sperm near the embryo sac. One sperm fertilizes the egg, forming the diploid zygote. The other contributes its haploid nucleus to the large diploid central cell of the embryo sac. This cell, now with a triploid ($3n$) nucleus, will give rise to a food-storing tissue called **endosperm**.

The union of two sperm cells with different nuclei of the embryo sac is called **double fertilization**, and the resulting production of endosperm is unique to angiosperms. Endosperm will develop only in ovules containing a fertilized egg, thereby preventing angiosperms from squandering nutrients.



▲ **Figure 15.6** Gametophyte development and fertilization in an angiosperm

? Fertilization unites the sperm cell, which develops within the male gametophyte (or), with the egg cell, which develops within the female gametophyte (or).

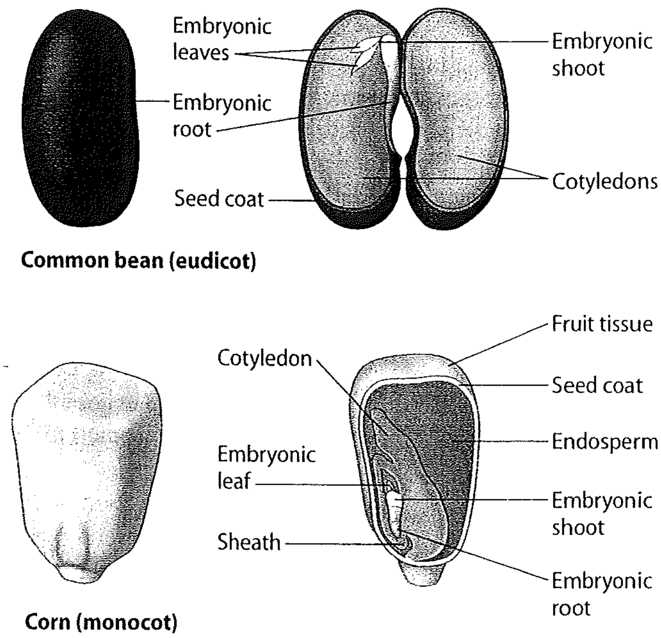
pollen grain · · · embryo sac

15.7 The ovule develops into a seed

After fertilization, the ovule, containing the triploid central cell and the diploid zygote, begins developing into a seed. As the embryo develops from the zygote, the seed stockpiles proteins, oils, and starch to varying degrees, depending on the species. This is what makes seeds such a major source of nutrition for many animals.

As shown in **Figure 15.7A**, embryonic development begins when the zygote divides by mitosis into two cells. Repeated division of one of the cells then produces a ball of cells that becomes the embryo. The other cell divides to form a thread of cells that pushes the embryo into the endosperm. The bulges you see on the embryo are the developing cotyledons. You can tell that the plant in this drawing is a eudicot, since it has two cotyledons.

The result of embryonic development in the ovule is a mature seed (Figure 15.7A, bottom right). Near the end of its maturation, the seed loses most of its water and forms a hard, resistant **seed coat** (brown). The embryo, surrounded by its endosperm food supply (gold), becomes dormant; it will not develop further until the seed germinates. Seed dormancy, a condition in which growth and development are suspended temporarily, is a key developmental adaptation. Dormancy allows time for a plant to disperse its seeds and increases the chance that a new generation of plants will begin growing only when environmental conditions, such as temperature and moisture, favor survival.

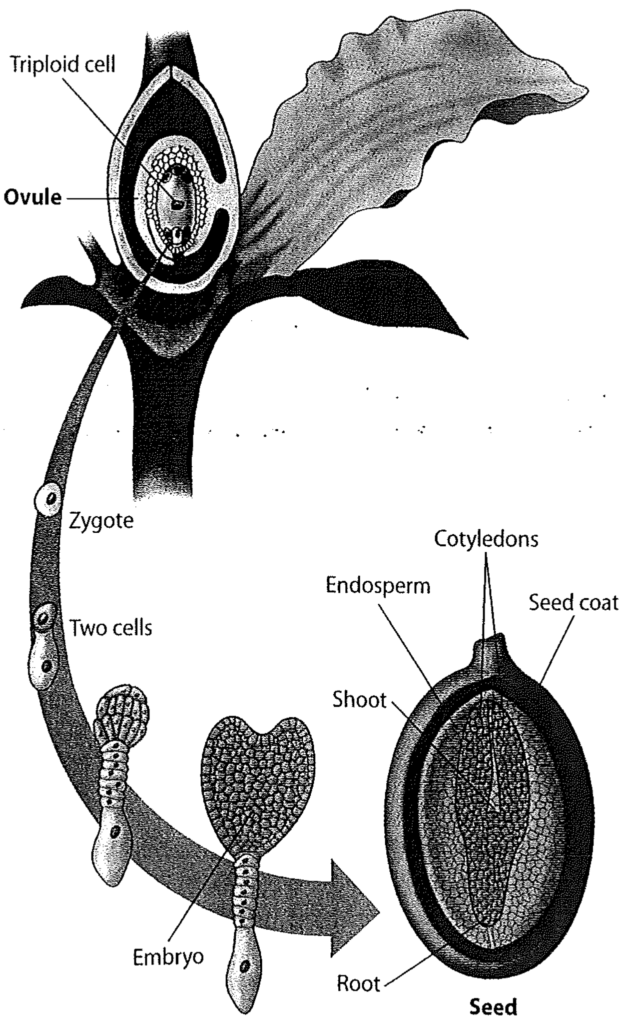


▲ **Figure 15.7B** Seed structure

The dormant embryo contains a miniature root and shoot, each equipped with an apical meristem. After the seed germinates, the apical meristems will sustain primary growth as long as the plant lives. Also present in the embryo are the three tissues that will form the epidermis, cortex, and primary vascular tissues.

Figure 15.7B contrasts the internal structures of eudicot and monocot seeds. In the eudicot (a bean), the embryo is an elongated structure with two thick cotyledons (tan). The embryonic root develops just below the point at which the cotyledons are attached to the rest of the embryo. The embryonic shoot, tipped by a pair of miniature embryonic leaves, develops just above the point of attachment. The bean seed contains no endosperm because its cotyledons absorb the endosperm nutrients as the seed forms. The nutrients start passing from the cotyledons to the embryo when it germinates.

A kernel of corn, an example of a monocot, is actually a fruit containing one seed. Everything you see in the drawing is the seed, except the kernel's outermost covering. The covering is dried fruit tissue, the former wall of the ovary, and is tightly bonded to the seed coat. Unlike the bean, the corn seed contains a large endosperm and a single, thin cotyledon. The cotyledon absorbs the endosperm's nutrients during germination. Also unlike the bean, the embryonic root and shoot in corn each have a protective sheath.



▲ **Figure 15.7A** Development of a eudicot plant embryo

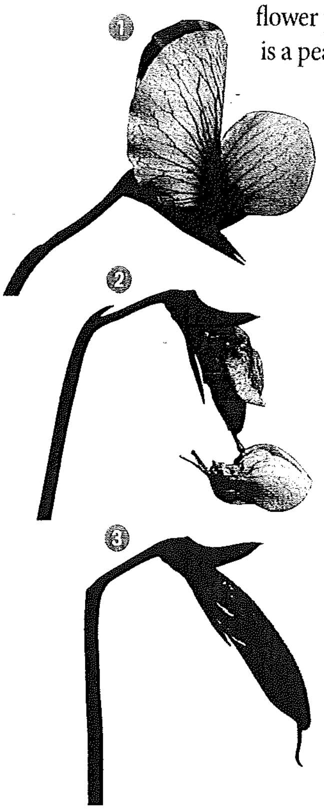
? **What is the role of the endosperm in a seed?**

The endosperm provides nutrients to the developing embryo.

15.8 The ovary develops into a fruit

In the previous two modules, we followed the angiosperm life cycle from the flower on the sporophyte plant through the transformation of an ovule into a seed. While the seeds are developing from ovules, hormonal changes triggered by fertilization cause the flower's ovary to thicken and mature into a fruit. A **fruit** is a specialized vessel that houses and protects seeds and helps disperse them from the parent plant. Although a fruit typically consists of a mature ovary, it can include other flower parts as well. A pea pod is a fruit, as is a peach, orange, tomato, cherry, or corn kernel.

The photographs in **Figure 15.8A** illustrate the changes in a pea plant leading to pod formation. ① Soon after pollination, ② the flower drops its petals, and the ovary starts to grow. The ovary expands tremendously, and its wall thickens, ③ forming the pod, or fruit, which holds the peas, or seeds.

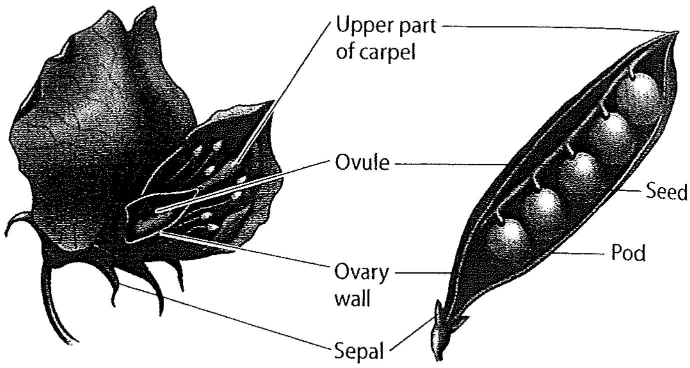


▲ **Figure 15.8A** Development of a fruit, a pea pod

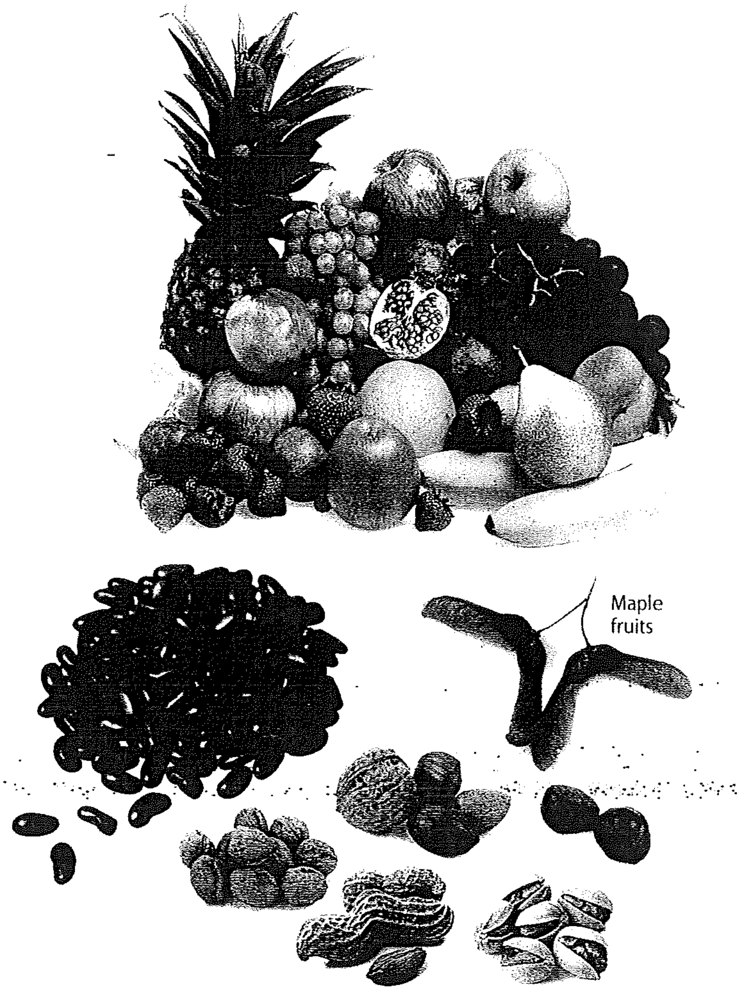
Figure 15.8B matches the parts of a pea flower with what they become in the pod. The wall of the ovary becomes the pod. The ovules, within the ovary, develop into the seeds. The small, thread-like structure at the end of the pod is what remains of the upper part of the flower's carpel. The sepals of the flower often stay attached to the base of the green pod. Peas are usually harvested at this stage of fruit development. If the pods are allowed to develop further, they become dry and brownish and will split open, releasing the seeds.

As shown in the examples in **Figure 15.8C**, mature fruits can be either fleshy or dry. Oranges, plums, and grapes are examples of fleshy fruits, in which the wall of the ovary becomes soft during ripening. Dry fruits include beans, nuts, and grains. The dry, wind-dispersed fruits of grasses, harvested while on the plant, are major staple foods for humans. The cereal grains of wheat, rice, corn, and other grasses, though easily mistaken for seeds, are each actually a fruit with a dry outer covering (the former wall of the ovary) that adheres to the seed coat of the seed within.

Various adaptations of fruits help disperse seeds. The seeds of some flowering plants, such as dandelions and maples, are contained within fruits that function like kites or propellers, adaptations that enhance dispersal by wind. Some fruits, such as coconuts, are adapted to dispersal by water. And many angiosperms rely on animals to carry seeds. Some of these plants have fruits modified as burrs that cling to animal fur (or the clothes of humans). Other angiosperms produce edible fruits, which are usually nutritious, sweet tasting, and vividly colored, advertising their ripeness. When an animal eats the fruit, it digests the fruit's fleshy part, but the tough seeds usually pass unharmed through the animal's digestive tract. Animals may deposit the seeds, along with a supply of fertilizer, kilometers from where the fruit was eaten.



▲ **Figure 15.8B** The correspondence between flower and fruit in the pea plant



▲ **Figure 15.8C** A collection of fleshy (top) and dry (bottom) fruits

? Seed is to _____ as _____ is to ovary.

ovule · · · fruit

15.9 Seed germination continues the life cycle

The germination of a seed is often used to symbolize the beginning of life, but as we have seen, the seed already contains a miniature plant, complete with embryonic root and shoot. Thus, at germination, the plant does not begin life but rather resumes the growth and development that were temporarily suspended during seed dormancy.

Germination usually begins when the seed takes up water. The hydrated seed expands, rupturing its coat. The inflow of water triggers metabolic changes in the embryo that make it start growing again. Enzymes begin digesting stored nutrients in the endosperm or cotyledons, and these nutrients are transported to the growing regions of the embryo.

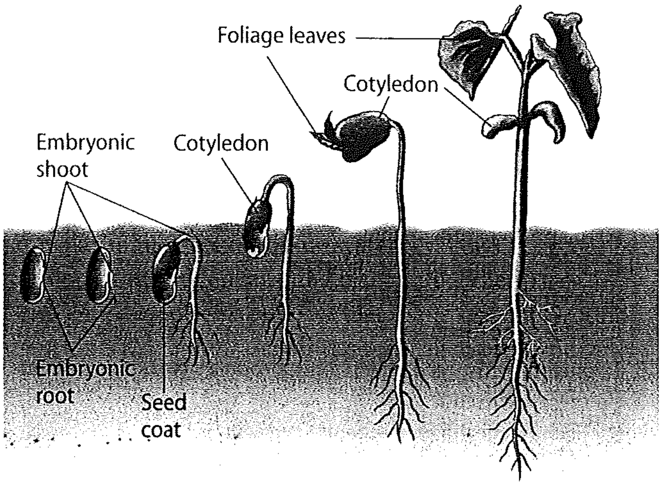
The figures below trace germination in a eudicot (a garden bean) and a monocot (corn). In **Figure 15.9A**, notice that the embryonic root of a bean emerges first and grows downward from the germinating seed. Next, the embryonic shoot emerges, and a hook forms near its tip. The hook protects the delicate shoot tip by holding it downward, rather than pushing it up through the abrasive soil. As the shoot breaks through the soil surface, its tip is lifted gently out of the soil as exposure to light stimulates the hook to straighten. The first foliage leaves then expand from the shoot tip and begin making food by photosynthesis. The cotyledons emerge from the soil and become leaflike photosynthetic structures. In many other plants, such as peas, the cotyledons remain behind in the soil and decompose.

Corn and other monocots use a different mechanism for breaking ground at germination **(Figure 15.9B)**. A protective sheath surrounding the shoot pushes upward and breaks through the soil. The shoot tip then grows up through the tunnel provided by the sheath. The corn cotyledon remains in the soil and decomposes.

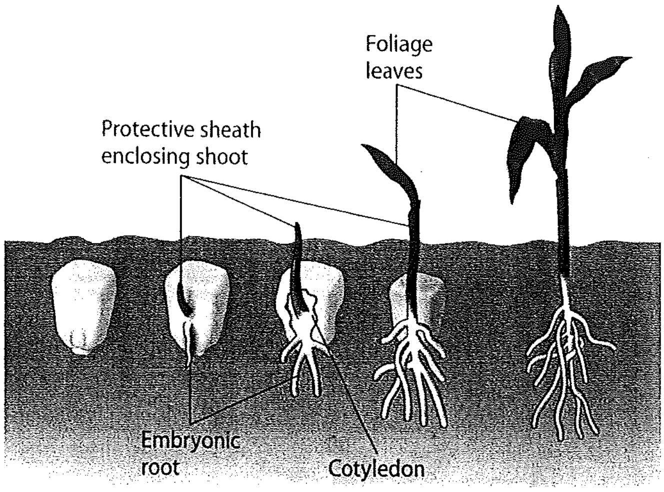
In the wild, only a small fraction of fragile seedlings endure long enough to reproduce. Production of enormous numbers of seeds compensates for the odds against individual survival.

? Which meristems provide additional cells for early growth of a seedling after germination?

The apical meristems of the shoot and root.



▲ **Figure 15.12A** Bean germination (a eudicot)



▲ **Figure 15.12B** Corn germination (a monocot)

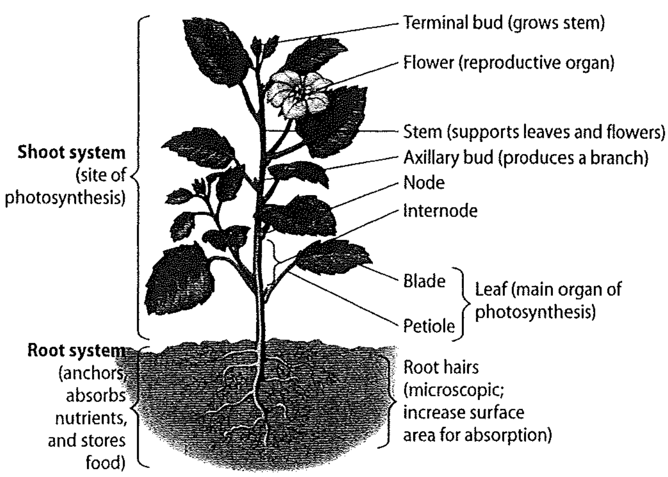
CHAPTER 15 REVIEW

Reviewing the Concepts

Plant Structure and Function (15.1–15.4)

15.1 The two major groups of angiosperms are the monocots and the eudicots. These two groups differ in the number of seed leaves and the structure of roots, stems, leaves, and flowers.

15.2 A typical plant body contains three basic organs: roots, stems, and leaves. The structure of a flowering plant allows it to draw resources from both soil and air.

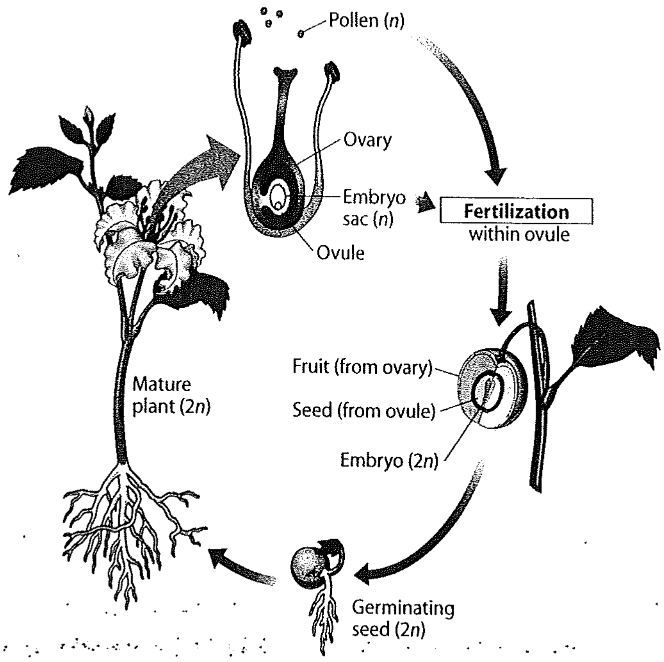


15.3 Three tissue systems make up the plant body. Roots, stems, and leaves are each made up of dermal, vascular, and ground tissues. Dermal tissue covers and protects the plant. In leaves, dermal tissue has stomata, pores with guard cells that regulate exchange of gases and water vapor with the environment. The vascular tissue system contains xylem and phloem, which function in support and transport. Xylem conveys water and dissolved minerals, and phloem transports sugars. The ground tissue system functions in storage, photosynthesis, and support.

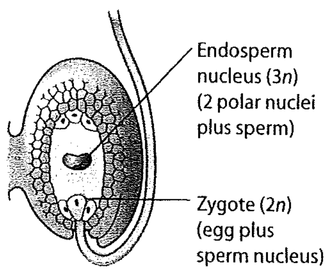
15.4 Plant cells are diverse in structure and function. The major types of plant cells are parenchyma, collenchyma, sclerenchyma (including fiber and sclereid cells), water-conducting cells (tracheids and vessel elements), and food-conducting cells (sieve-tube elements).

Reproduction of Flowering Plants (15.5–15.9)

15.5 The flower is the organ of sexual reproduction in angiosperms. The angiosperm flower consists of sepals, petals, stamens, and carpels. Pollen grains develop in anthers, at tips of stamens. The tip of the carpel, the stigma, receives pollen grains. The ovary, at the carpel's base, houses the egg-producing ovule.



15.6 The development of pollen and ovules culminates in fertilization. Haploid spores are formed within ovules and anthers. The spores in anthers give rise to male gametophytes—pollen grains—which produce sperm. A spore in an ovule produces the embryo sac, the female gametophyte. Each embryo sac has an egg cell. Pollination is the arrival of pollen grains onto a stigma. A pollen tube grows into the ovule, and sperm pass through it and fertilize both the egg and a second cell. This process is called double fertilization.



15.7 The ovule develops into a seed. After fertilization, the ovule becomes a seed, and the fertilized egg within it divides and becomes an embryo. The other fertilized cell develops into the endosperm, which stores food for the embryo.

15.8 The ovary develops into a fruit. Fruits help protect and disperse seeds.

15.9 Seed germination continues the life cycle. A seed starts to germinate when it takes up water and expands. The embryo resumes growth and absorbs nutrients from the endosperm. An embryonic root emerges, and a shoot pushes upward and expands its leaves.

Connecting the Concepts

1. Create a diagram that shows the relationships between the following: root system, root hairs, shoot system, leaves, petioles, blades, stems, nodes, internodes, flowers.

Testing Your Knowledge

Multiple Choice

2. Which of the following is closest to the center of a woody stem? (*Explain your answer.*)
   a. vascular cambium
   b. primary phloem
   c. secondary phloem
   d. primary xylem
   e. secondary xylem
3. A pea pod is formed from ______. A pea inside the pod is formed from ______.
   a. an ovule . . . a carpel
   b. an ovary . . . an ovule
   c. an ovary . . . a pollen grain
   d. an anther . . . an ovule
   e. endosperm . . . an ovary
4. While walking in the woods, you encounter an unfamiliar non-woody flowering plant. If you want to know whether it is a monocot or eudicot, it would *not* help to look at the
   a. number of seed leaves, or cotyledons, present in its seeds.
   b. shape of its root system.
   c. number of petals in its flowers.
   d. arrangement of vascular bundles in its stem.
   e. size of the plant.
5. In angiosperms, each pollen grain produces two sperm. What do these sperm do?
   a. Each one fertilizes a separate egg cell.
   b. One fertilizes an egg, and the other fertilizes the fruit.
   c. One fertilizes an egg, and the other is kept in reserve.
   d. Both fertilize a single egg cell.
   e. One fertilizes an egg, and the other fertilizes a cell that develops into stored food.

Matching

6. Attracts pollinator	a. pollen grain
7. Develops into seed	b. ovule
8. Protects flower before it opens	c. anther
9. Produces sperm	d. ovary
10. Produces pollen	e. sepal
11. Houses ovules	f. petal

Describing, Comparing, and Explaining

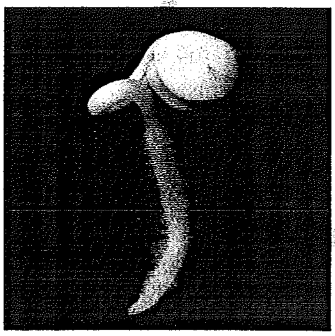
12. How does a fruit develop from a flower?
13. What part of a plant are you eating when you consume each of the following: celery stalk, peanut, strawberry, lettuce, beet?

Answers to all questions can be found in Appendix 1.

CHAPTER

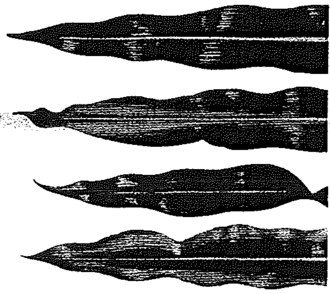
16 Plant Nutrition and Transport

BIG IDEAS



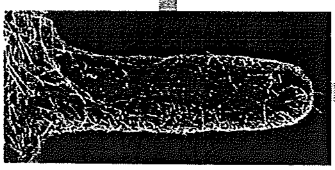
The Uptake and Transport of Plant Nutrients
(16.1)

Plants absorb and transport substances—such as water, minerals, CO_2, and sugar—required for growth.



Plant Nutrients and the Soil
(16.2–16.3)

Plants require many essential minerals for proper health.



Plant Nutrition and Symbiosis
(16.4)

Plants have developed relationships with bacteria, fungi, animals, and other plants.

The Uptake and Transport of Plant Nutrients

16.1 Plants acquire nutrients from air, water, and soil

Watch a plant grow from a tiny seed, and you can't help wondering where all the mass comes from. If you had to take a guess, what would you think is the source of the raw materials that make up a plant's body? Soil? Water? Air?

Aristotle thought that soil provided all the substance for plant growth. The 17th-century physician Jan Baptista van Helmont performed an experiment to test this hypothesis. He planted a willow seedling in a pot containing 91 kg of soil. After five years, the willow had grown into a tree weighing 76.8 kg, but only 0.06 kg of soil had disappeared from the pot. Van Helmont concluded that the willow had grown mainly from added water. A century later, an English physiologist named Stephen Hales postulated that plants are nourished mostly by air.

As it turns out, there is truth in all these early hypotheses about plant nutrition; air, water, and soil all contribute to plant growth **(Figure 16.1A)**. A plant's leaves absorb carbon dioxide (CO_2) from the air; in fact, about 96% of a plant's dry weight is organic (carbon-containing) material built mainly from CO_2. Meanwhile, a plant gets water (H_2O), minerals, and some oxygen (O_2) from the soil.

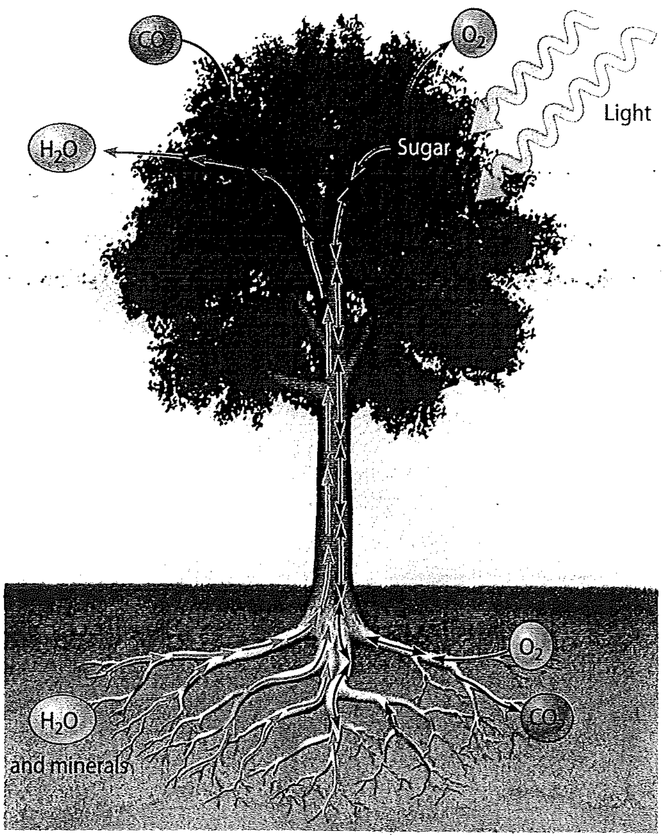
What happens to the materials a plant takes up from the air and soil? The sugars that a plant makes by photosynthesis are composed of the elements carbon, oxygen, and hydrogen. In Chapter 6, we saw that the carbon and oxygen used in photosynthesis come from atmospheric CO_2 and that the hydrogen comes from water molecules. Plant cells use the sugars made by photosynthesis in constructing all the other organic materials they need, but primarily for carbohydrates. The trunk of the giant sequoia tree in **Figure 16.1B**, for instance, consists mainly of sugar derivatives, such as the cellulose of cell walls.

Plants use cellular respiration to break down some of the sugars they make, obtaining energy from them in a process that consumes O_2. A plant's leaves take up some O_2 from the air, but Figure 16.1A does not show this because plants are actually net producers of O_2, giving off more of this gas than they use. When water is split during photosynthesis, O_2 gas is produced and released through the leaves. The O_2 being taken up from the soil by the plant's roots in Figure 16.1A is actually atmospheric O_2 that has diffused into the soil; it is used in cellular respiration in the roots themselves.

A plant's ability to move water from its roots to its leaves and its ability to deliver sugars to specific areas of its body are staggering feats of developmental engineering. Figure 16.1B highlights an extreme example; the topmost leaves of a giant sequoia can be over 100 m (300 feet) above the roots. In the next modules, we follow the movement of water, dissolved mineral nutrients, and sugar throughout the plant body.

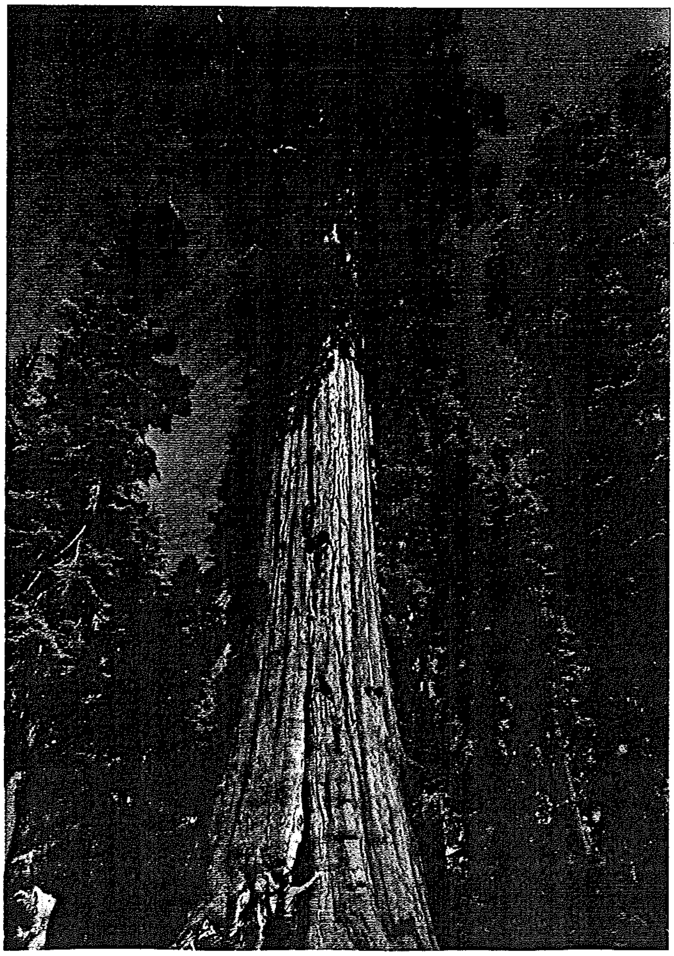
? **What inorganic substance is obtained in the greatest quantities from the soil?**

Water.



▲ **Figure 16.1A** The uptake of nutrients by a plant

▼ **Figure 16.1B** A giant sequoia, a product of photosynthesis



Plant Nutrients and the Soil

16.2 Plant health depends on a complete diet of essential inorganic nutrients

In contrast to animals, which require a diet of complex organic (carbon-containing) foods, plants survive and grow solely on CO_2 and inorganic substances (that is, plants are autotrophs; see Module 6.1). The ability of plants to assimilate CO_2 from the air, extract water and inorganic ions from the soil, and synthesize organic compounds is essential not only to the survival of plants but also to the survival of humans and other animals.

A chemical element is considered an **essential element** if a plant must obtain it from its environment to complete its life cycle—that is, to grow from a seed and produce another generation of seeds. A method called hydroponic culture can be used to determine which chemical elements are essential nutrients. As shown in **Figure 16.2**, plants are grown without soil by bathing the roots in mineral solutions. Air is bubbled into the water to give the roots oxygen for cellular respiration. By omitting a particular element from the medium, a researcher can test whether that element is essential to the plant.

If the element left out of the solution is an essential nutrient, then the incomplete medium will make the plant abnormal in appearance compared with control plants grown on a complete nutrient medium. The most common symptoms of a nutrient deficiency are stunted growth and discolored leaves. Hydroponic culture studies have helped identify 17 essential elements needed by all plants. Most research has involved crop plants and houseplants; little is known about the nutritional needs of uncultivated plants.

Nine of the essential elements are called **macronutrients** because plants require relatively large amounts of them. Six of the nine macronutrients—carbon, oxygen, hydrogen, nitrogen, sulfur, and phosphorus—are the major ingredients of organic compounds forming the structure of a plant. These six elements make up almost 98% of a plant's dry weight. The other three macronutrients—calcium, potassium, and magnesium—make up another 1.5%.

How does a plant use calcium, potassium, and magnesium? Calcium has several functions. For example, it is important in the formation of cell walls, and it combines with certain proteins to form the glue that holds plant cells together in tissues. Calcium also helps maintain the structure of cell membranes and helps regulate their selective permeability. Potassium is crucial as a cofactor required for the activity of several enzymes. A cofactor is an atom or molecule that cooperates with an enzyme in catalyzing a reaction. Potassium is also the main solute for osmotic regulation in plants. Potassium ion movements regulate the opening and closing of stomata. Magnesium is a component of chlorophyll and thus essential for photosynthesis.

Elements that plants need in very small amounts are called **micronutrients**. The eight known micronutrients are chlorine, iron, manganese, boron, zinc, copper, nickel, and molybdenum. Micronutrients function in plants mainly as cofactors. Iron, for example, is a component of cytochromes, proteins in the electron transport chains of chloroplasts and mitochondria. Micronutrients can generally be used over and over, so plants need only minute quantities of these elements. The requirement for molybdenum, for example, is so modest that there is only one atom of this rare element for every 60 million atoms of hydrogen in dried plant material. Yet a deficiency of molybdenum or any other micronutrient can weaken or kill a plant.

▲ **Figure 16.2** A hydroponic culture experiment

You conduct an experiment like the one in Figure 16.6 to test whether a certain plant species requires a particular chemical element as a micronutrient. Why is it important that the glassware be completely clean?

Because micronutrients are required in only minute amounts, even the smallest amount of dirt in the experimental flask may contain enough of the element you are testing to allow normal growth and invalidate your results.

16.3 Fertile soil supports plant growth

Along with climate, the major factor determining whether a plant can grow well in a particular location is the quality of the soil. Fertile soil can support abundant plant growth by providing conditions that enable plant roots to absorb water and dissolved nutrients.

Distinct layers of soil are visible in a road cut or deep hole, such as the cross section shown in **Figure 16.3A**. You can see three distinct soil layers, called horizons, in the cut. The A horizon, or **topsoil**, is subject to extensive weathering (freezing, drying, and erosion, for example). Topsoil is a mixture of rock particles of various sizes, living organisms, and **humus**, the remains of partially decayed organic material produced by the decomposition of dead organisms, feces, fallen leaves, and other organic matter by bacteria and fungi. The rock particles provide a large surface area that retains water and minerals while also forming air spaces containing oxygen that can diffuse into plant roots. Fertile topsoil is home to an astonishing number—about 5 billion per teaspoon—and variety of bacteria, algae and other protists, fungi, and small animals such as earthworms, roundworms, and burrowing insects. Along with plant roots, these organisms loosen and aerate the soil and contribute organic matter to the soil as they live and die. Nearly all plants depend on bacteria and fungi in the soil to break down organic matter into inorganic molecules that roots can absorb. Besides providing nutrients, humus also tends to retain water while keeping the topsoil porous enough for good aeration of the plant roots. Topsoil is rich in organic materials and is therefore most important for plant growth. Plant roots branch out in the A horizon and usually extend into the next layer, the B horizon.

The soil's B horizon contains many fewer organisms and much less organic matter than the topsoil and is less subject to weathering. Fine clay particles and nutrients dissolved in soil water drain down from the topsoil and often accumulate in the B horizon. The C horizon is composed mainly of partially broken-down rock that serves as the "parent" material for the upper layers of soil.

Figure 16.3B illustrates the intimate association between a plant's root hairs, soil water, and the tiny particles of topsoil. The root hairs are in direct contact with the water that surrounds the particles. The soil water is not pure but a solution containing dissolved inorganic ions. Oxygen diffuses into the water from small air spaces in the soil. Roots absorb this soil solution.

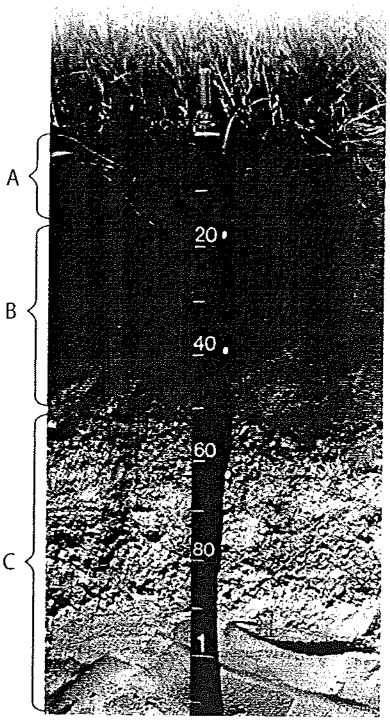
Cation exchange is a mechanism by which the root hairs take up certain positively charged ions (cations). Inorganic cations—such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+)—adhere by electrical attraction to the negatively charged surfaces of clay particles. This adhesion helps prevent these positively charged nutrients from draining away during heavy rain or irrigation. In cation exchange **(Figure 16.3C)**, root hairs release hydrogen ions (H^+) into the soil solution. The hydrogen ions displace cations on the clay particle surfaces, and root hairs can then absorb them.

In contrast to cations, negative ions (anions)—such as nitrate (NO_3^-)—are usually not bound tightly by soil particles. Unbound ions are readily available to plants, but they tend to drain out of the soil quickly due to irrigation or rainfall. If they do, the soil may become deficient in nitrogen.

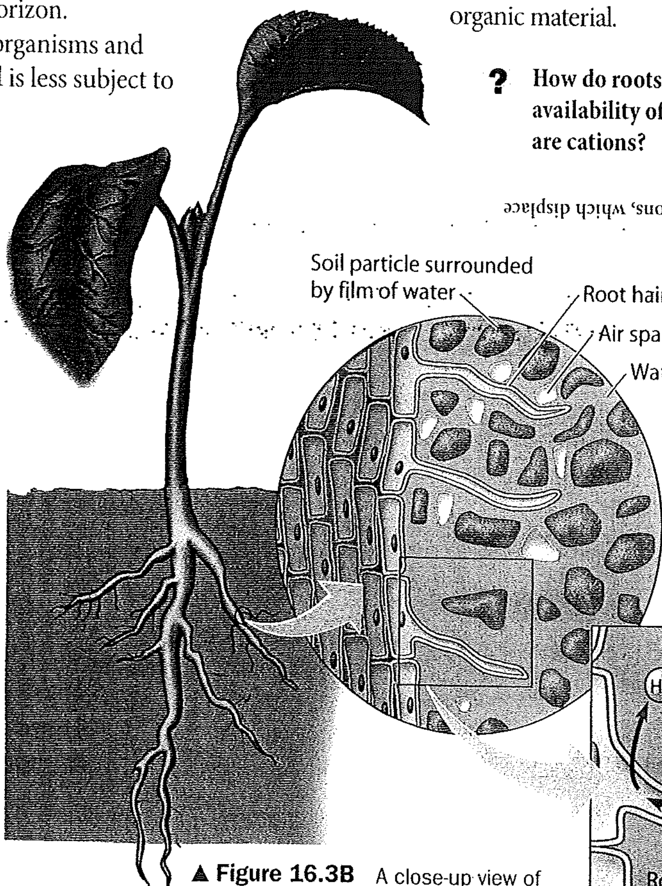
It may take centuries for a soil to become fertile through the breakdown of rock and the accumulation of organic material.

? How do roots actively increase the availability of mineral nutrients that are cations?

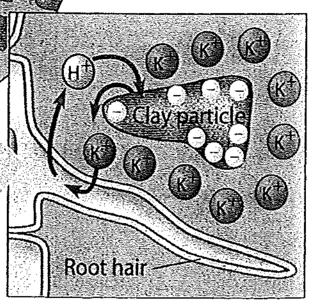
By secreting hydrogen ions, which displace cations from soil particles.



▲ **Figure 16.3A** Three soil horizons visible beneath grass



▲ **Figure 16.3B** A close-up view of root hairs in soil



▲ **Figure 16.3C** Cation exchange

Plant Nutrition and Symbiosis

16.4 Most plants depend on bacteria to supply nitrogen

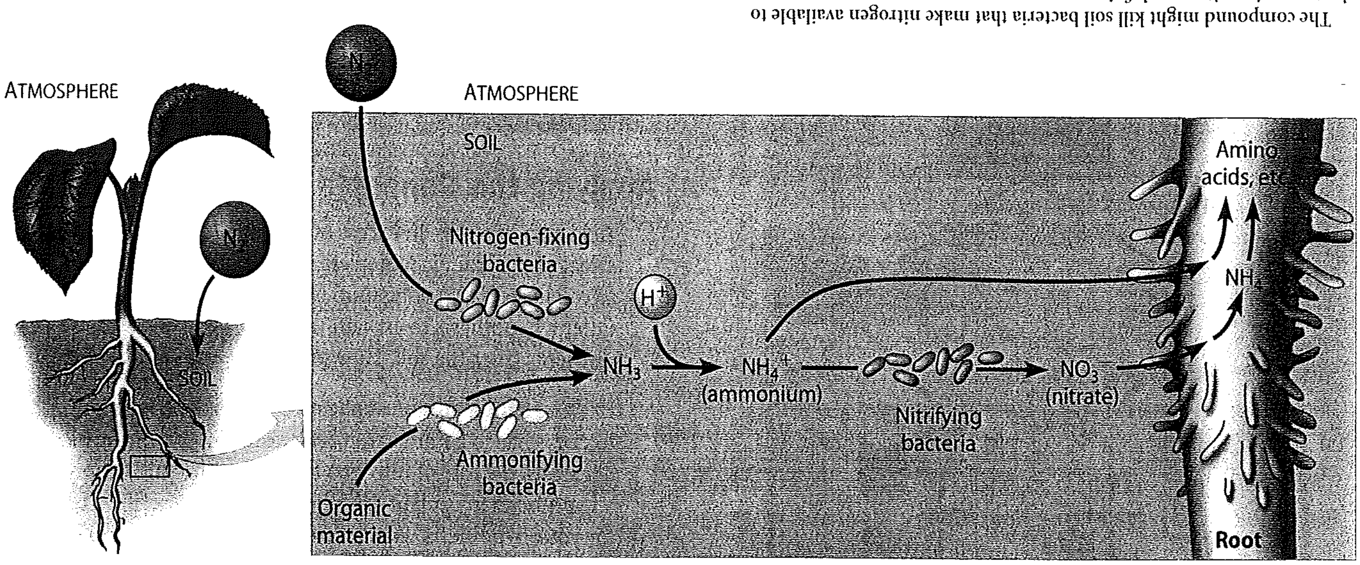
Nitrogen deficiency is the most common nutritional problem in plants. This is puzzling when you consider that the atmosphere is nearly 80% nitrogen. But even though plants are bathed in gaseous nitrogen (N_2), they cannot absorb it directly from the air. To be used by plants, N_2 must be converted to ammonium (NH_4^+) or nitrate (NO_3^-).

Within soil, ammonium and nitrate are produced from atmospheric N_2 or from organic matter by bacteria. As shown in **Figure 16.4**, certain soil bacteria, called nitrogen-fixing bacteria, convert atmospheric N_2 to ammonia (NH_3), a metabolic process called **nitrogen fixation**. In soil, ammonia picks up an H^+ to form an ammonium ion (NH_4^+). A second group of bacteria, called ammonifying bacteria, adds to the soil's supply of ammonium by decomposing organic matter.

Plant roots can absorb nitrogen as ammonium. However, plants acquire their nitrogen mainly in the form of nitrate (NO_3^-), which is produced in the soil by a third group of soil bacteria called nitrifying bacteria. After nitrate is absorbed by roots, enzymes within plant cells convert the nitrate back to ammonium, which is then incorporated into amino acids. Thus, were it not for soil bacteria, most plants would starve for nitrogen even though they are surrounded by it in huge quantities.

? What is the danger in applying a compound that kills bacteria to the soil around plants?

The compound might kill soil bacteria that make nitrogen available to plants, causing nitrogen deficiency.



▲ **Figure 16.4** The roles of bacteria in supplying nitrogen to plants

CHAPTER 16 REVIEW

Reviewing the Concepts

The Uptake and Transport of Plant Nutrients (16.1)

16.1 Plants acquire nutrients from air, water, and soil. As a plant grows, its roots absorb water, minerals (inorganic ions), and some O_2 from the soil. Its leaves take in carbon dioxide from the air.

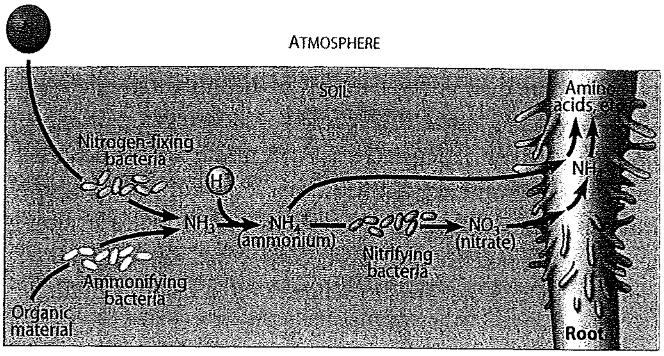
Plant Nutrients and the Soil (16.2–16.3)

16.2 Plant health depends on a complete diet of essential inorganic nutrients. A plant must obtain usable sources of the chemical elements—inorganic nutrients—it requires from its surroundings. Macronutrients, such as carbon and nitrogen, are needed in large amounts, mostly to build organic molecules. Micronutrients, including iron and zinc, act mainly as cofactors of enzymes.

16.3 Fertile soil supports plant growth. Fertile soil contains a mixture of small rock and clay particles that hold water and ions and also allow O_2 to diffuse into plant roots. Humus (decaying organic material) provides nutrients and supports the growth of organisms that enhance soil fertility. Anions (negatively charged ions), such as nitrate (NO_3^-), are readily available to plants because they are not bound to soil particles. However, anions tend to drain out of soil rapidly. Cations (positively charged ions), such as K^+, adhere to soil particles. In cation exchange, root hairs release H^+, which displaces cations from soil particles; the root hairs then absorb the free cations.

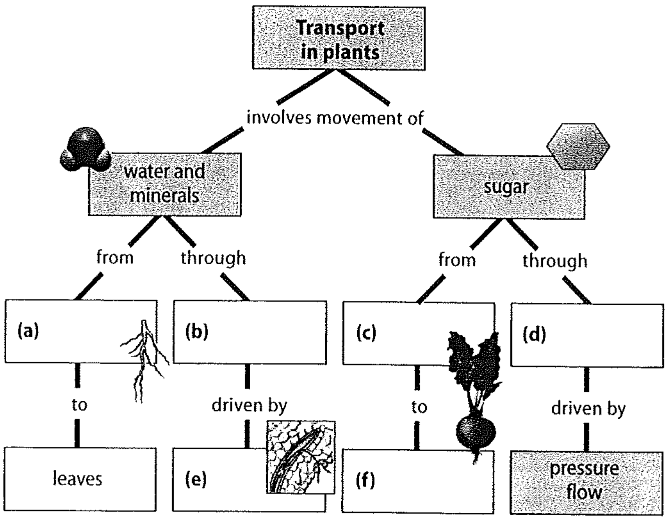
Plant Nutrition and Symbiosis (16.4)

16.4 Most plants depend on bacteria to supply nitrogen. Relationships with other organisms help plants obtain nutrients. Bacteria in the soil convert atmospheric N_2 to forms that can be used by plants.



Connecting the Concepts

1. Fill in the blanks in this concept map to help you tie together key concepts concerning transport in plants.



Testing Your Knowledge

Multiple Choice

2. Plants require the smallest amount of which of the following nutrients?
   a. oxygen
   b. phosphorus
   c. carbon
   d. iron
   e. hydrogen
3. Which of the following activities of soil bacteria does *not* contribute to creating usable nitrogen supplies for plant use?
   a. the fixation of atmospheric nitrogen
   b. the conversion of ammonium ions to nitrate ions
   c. the decomposition of dead animals
   d. the assembly of amino acids into proteins
   e. the generation of ammonium from proteins in dead leaves
4. By trapping insects, carnivorous plants obtain ______, which they need ______. (*Pick the best answer.*)
   a. water . . . because they live in dry soil
   b. nitrogen . . . to make sugar
   c. phosphorus . . . to make protein
   d. sugars . . . because they can't make enough by photosynthesis
   e. nitrogen . . . to make protein

Applying the Concepts

5. Acid rain contains an excess of hydrogen ions (H^+). One effect of acid rain is to deplete the soil of plant nutrients such as calcium (Ca^{2+}), potassium (K^+), and magnesium (Mg^{2+}). Offer a hypothesis to explain why acid rain washes these nutrients from the soil. How might you test your hypothesis?
6. In some situations, the application of nitrogen fertilizer to crops has to be increased each year because the fertilizer decreases the rate of nitrogen fixation in the soil. Propose a hypothesis to explain this phenomenon. Describe a test for your hypothesis. What results would you expect from your test?

Answers to all questions can be found in Appendix 1.

APPENDIX 1 Chapter Review Answers

Chapter 1

1. The vertical scale of biology refers to the hierarchy of biological organization: from molecules to organelles, cells, tissues, organs, organ systems, organisms, populations, communities, ecosystems, and the biosphere. At each level, emergent properties arise from the interaction and organization of component parts. The horizontal scale of biology refers to the incredible diversity of living organisms, past and present, including the 1.8 million species that have been named so far. Biologists divide these species into three domains—Bacteria, Archaea, and Eukarya—and organize them into kingdoms and other groups that attempt to reflect evolutionary relationships.
2. a. life; b. evolution; c. natural selection; d. unity of life; e. three domains (or numerous kingdoms; 1.8 million species)
3. d 4. c 5. e (You may have been tempted to choose b, the molecular level. However, protists may have chemical communication or interactions with other protists. No protists, however, have organs.) 6. d 7. c 8. b 9. d
10. Both energy and chemical nutrients are passed through an ecosystem from producers to consumers to decomposers. But energy enters an ecosystem as sunlight and leaves as heat. Chemical nutrients are recycled from the soil or atmosphere through plants, consumers, and decomposers and returned to the air, soil, and water.
11. In pursuit of answers to questions about nature, a scientist uses a logical thought process involving these key elements: observations about natural phenomena, questions derived from observations, hypotheses posed as tentative explanations of observations, logical predictions of the outcome of tests if the hypotheses are correct, and actual tests of hypotheses. Scientific research is not a rigid method because a scientist must adapt these processes to the set of conditions particular to each study. Intuition, chance, and luck are also part of science.
12. Technology is the application of scientific knowledge. For example, the use of solar power to run a calculator or heat a home is an application of our knowledge, derived by the scientific process, of the nature of light as a type of energy and how light energy can be converted to other forms of energy. Another example is the use of DNA to insert new genes into crop plants. This process, often called genetic engineering, stems from decades of scientific research on the structure and function of DNA from many kinds of organisms.
13. a. Hypothesis: Giving rewards to mice will improve their learning. Prediction: If mice are rewarded with food, they will learn to run a maze faster.
    b. The control group was the mice that were not rewarded. Without them, it would be impossible to know if the mice that were rewarded decreased their time running the maze only because of practice.
    c. Both groups of mice should not have run the maze before and should be about the same age. Both experiments should be run at the same time of day and under the same conditions.
    d. Yes, the results fail to falsify the hypothesis because data show that the rewarded mice began to run the maze faster by day 3 and improved their performance (ran faster than the control mice) each day thereafter.
14. The researcher needed to compare the number of attacks on artificial king snakes with attacks on artificial brown snakes. It may be that there were simply more predators in the coral snake areas or that the predators were hungrier than the predators in the other areas. The experiment needed a control and proper data analysis.
15. If these cell division control genes are involved in producing the larger tomato, they may have similar effects if transferred to other fruits or vegetables. Cancer is a result of uncontrolled cell division. One could see if there are similarities between the tomato genes and any human genes that could be related to human development or disease. The control of cell division is a fundamental process in growth, repair, and asexual reproduction—all important topics in biology.
16. Virtually any news report or magazine contains stories that are mainly about biology or at least have biological connections. How about biological connections in advertisements?

Chapter 2

1. Carbon forms four covalent bonds, either with other carbon atoms, producing chains or rings of various lengths and shapes, or with other atoms, such as characteristic chemical groups that confer specific properties on a molecule. This is the basis for the incredible diversity of organic compounds. Organisms can link a small number of monomers into different arrangements to produce a huge variety of polymers.
2. a. glucose; b. energy storage; c. cellulose; d. fats; e. cell membrane component; f. steroids; g. amino group; h. carboxyl group; i. R group; j. enzyme; k. structural protein; l. movement; m. hemoglobin; n. defense; o. phosphate group; p. nitrogenous base; q. ribose or deoxyribose; r. DNA; s. code for proteins
3. d (The second kind of molecule is a polymer of the first.) 4. c 5. d 6. c 7. a 8. b 9. e 10. d
11. Fats (triglycerides)—energy storage. Phospholipids—major components of membranes. Steroids—cholesterol is a component of animal cell membranes; other steroids function as hormones.

12. Weak bonds that stabilize the three-dimensional structure of a protein are disrupted, and the protein unfolds. Function depends on shape, so if the protein is the wrong shape, it won't function properly.

13. Proteins are made of 20 amino acids arranged in many different sequences into chains of many different lengths. Genes, defined stretches of DNA, dictate the amino acid sequences of proteins in the cell.

14. Proteins function as enzymes, which catalyze chemical reactions. They also function in structure, movement, transport, defense, signaling, signal reception, and storage of amino acids (see Module 2.12).

15. The sequence of nucleotides in DNA is transcribed into a sequence of nucleotides in RNA, which determines the sequence of amino acids that will be used to build a polypeptide. Proteins mediate all the activities of a cell; thus, by coding for proteins, DNA controls the functions of a cell.

16. This is a hydrolysis reaction, which consumes water. It is essentially the reverse of the diagram in Figure 2.5, except that fructose has a different shape than glucose.

17. Circle NH_2, an amino group; COOH, a carboxyl group; and OH, a hydroxyl group on the R group. This is an amino acid, a monomer of proteins. The OH group makes it a polar amino acid.

18. a. A: at about 37°C; B: at about 78°C.
    b. A: from humans (human body temperature is about 37°C); B: from thermophilic bacteria.
    c. Above 40°C, the human enzyme denatures and loses its shape and thus its function. The increased thermal energy disrupts the weak bonds that maintain secondary and tertiary structure in an enzyme.

19. Silicon has four electrons in its outer electron shell, as does carbon. One would predict that silicon could thus form complex molecules by binding with four partners. Neon has a filled outer shell and is nonreactive. Sulfur can only form two covalent bonds and thus would not have the versatility of carbon or silicon.

Chapter 3

1. a. nucleus; b. nucleolus; c. ribosomes; d. Golgi apparatus; e. plasma membrane; f. mitochondrion; g. cytoskeleton; h. peroxisome; i. centriole; j. lysosome; k. rough endoplasmic reticulum; l. smooth endoplasmic reticulum. For functions, see Table 3.15.

2. flagellum or cilia (some plant sperm cells have flagella), lysosome, centriole (involved with microtubule formation)

3. chloroplast, central vacuole, cell wall

4. b 5. d 6. e 7. a 8. c 9. b 10. d 11. c 12. d

13. DNA as genetic material, ribosomes, plasma membrane, and cytoplasm

14. Tight junctions form leakproof sheets of cells. Anchoring junctions link cells to each other; they form strong sheets of cells. Gap junctions are channels through which small molecules can move from cell to cell.

15. Both process energy. A chloroplast converts light energy to chemical energy (sugar molecules). A mitochondrion converts chemical energy (food molecules) to another form of chemical energy (ATP).

16. Different conditions and conflicting processes can occur simultaneously within separate, membrane-enclosed compartments. Also, there is increased area for membrane-attached enzymes that carry out metabolic processes.

17. Cilia may propel a cell through its environment or sweep a fluid environment past the cell.

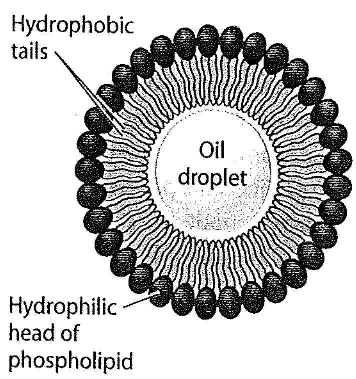
18. A protein inside the ER is packaged inside transport vesicles that bud off the ER and then join to the Golgi apparatus. A transport vesicle containing the finished protein product then buds off the Golgi and travels to and joins with the plasma membrane, expelling the protein from the cell.

19. Part true, part false. All animal and plant cells have mitochondria; plant cells but not animal cells have chloroplasts.

20. The plasma membrane is a phospholipid bilayer with the hydrophilic heads facing the aqueous environment on both sides and the hydrophobic fatty acid tails mingling in the center of the membrane. Proteins are embedded in and attached to this membrane. Microfilaments form a three-dimensional network just inside the plasma membrane. The extracellular matrix outside the membrane is composed largely of glycoproteins, which may be attached to membrane proteins called integrins. Integrins can transmit information from the ECM to microfilaments on the other side of the membrane.

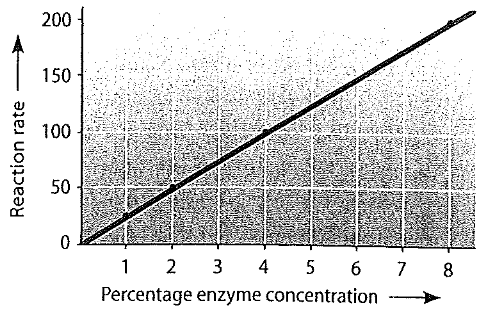
21. Individuals with PCD have nonfunctional cilia and flagella due to a lack of dynein motor proteins. This defect would also mean that the cilia involved in left-right pattern formation in the embryo would not be able to set up the fluid flow that initiates the normal arrangement of organs.

22. A single layer of phospholipids surrounding the oil droplet would have their hydrophobic fatty acid tails associated with the hydrophobic oil and their hydrophilic heads facing the aqueous environment of the cell outside the droplet.

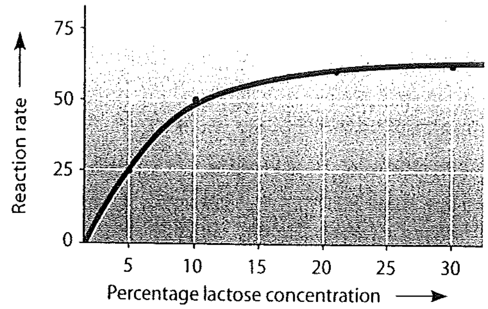


Chapter 4

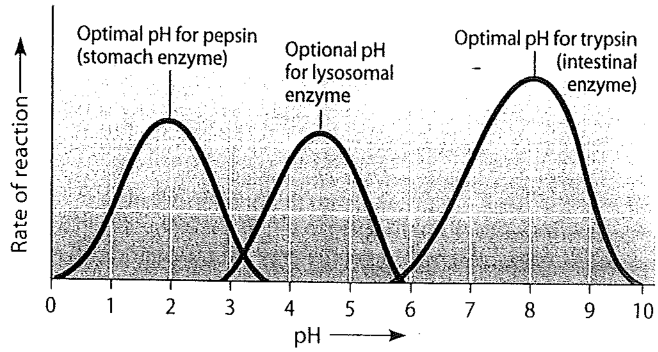
1. a. active transport; b. concentration gradient; c. small nonpolar molecules; d. facilitated diffusion; e. transport proteins
2. a. enzyme; b. active site of enzyme; c. substrate; d. substrate in active site; induced fit strains substrate bonds; e. substrate converted to products; f. product molecules released; enzyme is ready for next catalytic cycle
3. b **4.** d **5.** c (Only active transport can move solute against a concentration gradient.) **6.** d **7.** b
8. Aquaporins are water transport channels that allow for very rapid diffusion of water through a cell membrane. They are found in cells that have high water transport needs, such as blood cells, kidney cells, and plant cells.
9. The work of cells falls into three main categories: mechanical, chemical, and transport. ATP provides the energy for cellular work by transferring a phosphate group to a protein (movement and transport) or to a substrate (chemical).
10. Energy is stored in the chemical bonds of organic molecules. The barrier of E_A prevents these molecules from spontaneously breaking down and releasing that energy. When a substrate fits into an enzyme's active site with an induced fit, its bonds may be strained and thus easier to break, or the active site may orient two substrates in such a way as to facilitate the reaction.
11. Cell membranes are composed of a phospholipid bilayer with embedded proteins. The bilayer creates the hydrophobic boundary between cells and their surroundings (or between organelles and the cytoplasm). The proteins perform the many functions of membranes, such as enzyme action, transport, attachment, and signaling.
12. Inhibitors that are toxins or poisons irreversibly inhibit key cellular enzymes. Inhibitors that are designed as drugs are beneficial, such as when they interfere with the enzymes of bacterial or viral invaders or cancer cells. Cells use feedback inhibition of enzymes in metabolic pathways as important mechanisms that conserve resources.
13. Heating, pickling, and salting denature enzymes, changing their shapes so they do not fit substrates. Freezing decreases the kinetic energy of molecules, so enzymes are less likely to interact with their substrates.
14. a. The more enzyme present, the faster the rate of reaction, because it is more likely that enzyme and substrate molecules will meet.



b. The more substrate present, the faster the reaction, for the same reason, but only up to a point. An enzyme molecule can work only so fast; once it is saturated (working at top speed), more substrate does not increase the rate.



15. The black curve on the left would correspond to the stomach enzyme pepsin, which has a lower optimal pH, as is found in the stomach; the red curve on the right would correspond to trypsin, which has a higher optimal pH. The curve for a lysosomal enzyme should have an optimal pH at 4.5.



Chapter 5

1. a. glycolysis; b. citric acid cycle; c. oxidative phosphorylation; d. oxygen; e. electron transport chain; f. CO_2; g. H_2O
2. e **3.** c (NAD^+ and FAD, which are recycled by electron transport, are in limited supply in a cell.) **4.** e **5.** d **6.** c **7.** b (at the same time NADH is oxidized to NAD^+) **8.** a
9. Glycolysis is considered the most ancient because it occurs in all living cells and doesn't require oxygen or membrane-enclosed organelles.
10. Oxygen picks up electrons from the oxidation of glucose at the end of the electron transport chain. Carbon dioxide results from the oxidation of glucose. It is released in the oxidation of pyruvate and in the citric acid cycle.
11. In lactic acid fermentation (in muscle cells), pyruvate is reduced by NADH to form lactate, and NAD^+ is recycled.
12. As carbohydrates are broken down in glycolysis and the oxidation of pyruvate, glycerol can be made from G3P and fatty acids can be made from acetyl CoA. Amino groups, containing N atoms, must be supplied to various intermediates of glycolysis and the citric acid cycle to produce amino acids.
13. 100 kcal per day is 700 kcal per week. On the basis of Figure 6.4, walking 3 mph would require $\frac{700}{245}$ = about 2.8 hr; swimming, 1.7 hr; running, 0.7 hr.

14. NAD^+ and FAD are coenzymes that are not used up during the oxidation of glucose. NAD^+ and FAD are recycled when NADH and $FADH_2$ pass the electrons they are carrying to the electron transport chain. We need a small additional supply to replace those that are damaged.

15. a. No, this shows the blue color getting more intense. The reaction decolorizes the blue dye.
    b. No, this shows the dye being decolorized, but it also shows the three mixtures with different initial color intensities. The intensities should have started out the same, since all mixtures used the same concentration of dye.
    c. Correct. The mixtures all start out the same, and then the ones with more succinate (reactant) decolorize faster.

16. The presence of ATP synthase enzymes in prokaryotic plasma membranes and the inner membrane of mitochondria provides support for the theory of endosymbiosis—that mitochondria developed from an engulfed prokaryote that used aerobic respiration.

Chapter 6

1. a. electron transport chain; b. ATP synthase; c. thylakoid space; d. stroma; e. ATP. The higher H^+ concentration is found in the intermembrane space of the mitochondrion and in the thylakoid space of the chloroplast.

2. In mitochondria: a. Electrons come from food molecules. b. Electrons have high potential energy in the bonds in organic molecules. c. Electrons are passed to oxygen, which picks up H^+ and forms water.

   In chloroplasts: a. Electrons come from splitting of water. b. Light energy excites the electrons to a higher energy level. c. Electrons flow from water to the reaction-center chlorophyll in photosystem II to the reaction-center chlorophyll in photosystem I to $NADP^+$, reducing it to NADPH.

   In both processes: d. Energy released by redox reactions in the electron transport chain is used to transport H^+ across a membrane. The flow of H^+ down its concentration gradient back through ATP synthase drives the phosphorylation of ADP to make ATP.

3. a. light energy; b. light reactions; c. Calvin cycle; d. O_2 released; e. electron transport chain; f. NADPH; g. ATP; h. 3-PGA is reduced.

4. c 5. c 6. a 7. c (NADPH and ATP from the light reactions are required by the Calvin cycle.) 8. d 9. e 10. b 11. c

12. Light reactions: Light and water are inputs; ATP, NADPH, and O_2 are outputs. Calvin cycle: CO_2, ATP, and NADPH are inputs; G3P is the output. Also, ADP and $NADP^+$ are inputs to the light reactions and outputs of the Calvin cycle.

13. The light reactions require ADP and $NADP^+$, which are not recycled from ATP and NADPH when the Calvin cycle stops.

14. Plants can break down the sugar for energy in cellular respiration or use the sugar as a raw material for making other organic molecules. Excess sugar is stored as starch.

15. Some issues and questions to consider: What are the risks that we take and costs we must pay if global warming continues? How certain do we have to be that warming is caused by human activities before we act? What can we do to reduce CO_2 emissions? Is it possible that the costs and sacrifices of reducing CO_2 emissions might actually improve our lifestyle?

16. Some issues and questions to consider: How much land would be required for large-scale conversion to biofuel production, and would that detract from land needed to produce food? Are there fertilizer needs and waste disposal issues with biofuel production? Is there a difference in net input and output of CO_2 between production and use of fossil fuels and production and use of biofuels? Which one offers a more long-term solution to energy needs? How do other alternative energy sources compare in cost, potential problems and pollution, and benefit?

Chapter 7

1.

	Mitosis	Meiosis
Number of chromosomal duplications	1	1
Number of cell divisions	1	2
Number of daughter cells produced	2	4
Number of chromosomes in the daughter cells	*Diploid (2n)*	*Haploid (n)*
How the chromosomes line up during metaphase	*Singly*	*In tetrads (metaphase I), then singly (metaphase II)*
Genetic relationship of the daughter cells to the parent cell	*Genetically identical*	*Genetically unique*
Functions performed in the human body	*Growth, development, and repair*	*Production of gametes*

2. c 3. a 4. b 5. c 6. e (A diploid cell would have an even number of chromosomes; the odd number suggests that meiosis I has been completed. Sister chromatids are together only in prophase and metaphase of meiosis II.) 7. c 8. b 9. c 10. b

11. Mitosis without cytokinesis would result in a single cell with two nuclei. Multiple rounds of cell division like this could produce such a "megacell."

12. Interphase (for example, third column from left in micrograph, third cell from top): Growth; metabolic activity; DNA synthesis. Prophase (for example, second column, cell at bottom): Chromosomes shorten and thicken; mitotic spindle forms. Metaphase (for example, first column, middle cell): Chromosomes line up on a plane going through the cell's equator. Anaphase (for example, third column, second cell from top): Sister chromatids separate and move to the poles of the cell. Telophase (for example, fourth column, fourth complete cell from top): Daughter nuclei form around chromosomes; cytokinesis usually occurs.

13. A ring of microfilaments pinches an animal cell in two, a process called cleavage. In a plant cell, membranous vesicles form a disk called the cell plate at the midline of the parent cell, cell plate membranes fuse with the plasma membrane, and a cell wall grows in the space, separating the daughter cells.

14. Some possible hypotheses: The replication of the DNA of the bacterial chromosome takes less time than the replication of the DNA in a eukaryotic cell. The time required for a growing bacterium to roughly double its cytoplasm is much less than for a eukaryotic cell. Bacteria have a cell cycle control system much simpler than that of eukaryotes.

15. 1 cm^3 = 1,000 mm^3, so 5,000 mm^3 of blood contains 5,000 × 1,000 × 5,000,000 = 25,000,000,000,000, or 2.5×10^{13}, red blood cells. The number of cells replaced each day = $2.5 \times 10^{13}/120 = 2.1 \times 10^{11}$ cells. There are 24 × 60 × 60 = 86,400 seconds in a day. Therefore, the number of cells replaced each second = $2.1 \times 10^{11}/86{,}400$ = about 2×10^6, or 2 million. Thus, about 2 million cell divisions must occur each second to replace red blood cells that are lost.

Chapter 8

1. a. alleles; b. loci; c. homozygous; d. dominant; e. recesive; f. incomplete dominance

2. d 3. d (Neither parent is ruby-eyed, but some offspring are, so it is recessive. Different ratios among male and female offspring show that it is sex-linked.) 4. e

5. The parental gametes are *WS* and *ws*. Recombinant gametes are *Ws* and *wS*, produced by crossing over.

6. Height appears to be a quantitative trait resulting from polygenic inheritance, like human skin color.

7. The genotype of the black short-haired parent rabbit is *BBSS*. The genotype of the brown long-haired parent rabbit is *bbss*. The F_1 rabbits will all be black and short-haired, *BbSs*. The F_2 rabbits will be $\frac{9}{16}$ black short-haired, $\frac{3}{16}$ black long-haired, $\frac{3}{16}$ brown short-haired, and $\frac{1}{16}$ brown long-haired.

8. If the genes are not linked, the proportions among the offspring will be 25% gray red, 25% gray purple, 25% black red, 25% black purple. The actual percentages show that the genes are linked. The recombination frequency is 6%.

9. Start out by breeding the cat to get a population to work with. If the curl allele is recessive, two curl cats can have only curl kittens. If the allele is dominant, curl cats can have "normal" kittens. If the curl allele is sex-linked, ratios will differ in male and female offspring of some crosses. If the curl allele is autosomal, the same ratios will be seen among males and females. Once you have established that the curl allele is dominant and autosomal, you can determine if a particular curl cat is true-breeding (homozygous) by doing a testcross with a normal cat. If the curl cat is homozygous, all offspring of the testcross will be curl; if heterozygous, half of the offspring will be curl and half normal.

Chapter 9

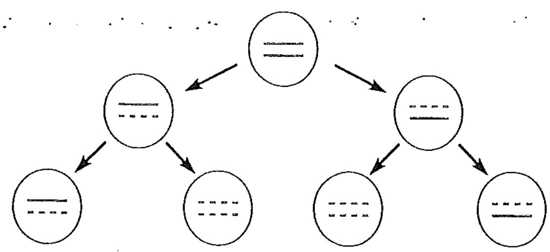
1. a. nucleotides; b. transcription; c. RNA polymerase; d. mRNA; e. rRNA; f. tRNA; g. translation; h. ribosomes; i. amino acids

2. e 3. b

4. Ingredients: Original DNA, nucleotides, several enzymes and other proteins, including DNA polymerase and DNA ligase. Steps: Original DNA strands separate at a specific site (origin of replication), free nucleotides hydrogen-bond to each strand according to base-pairing rules, and DNA polymerase covalently bonds the nucleotides to form new strands. New nucleotides are added only to the 3′ end of a growing strand. One new strand is made in one continuous piece; the other new strand is made in a series of short pieces that are then joined by DNA ligase. Product: Two identical DNA molecules, each with one old strand and one new strand.

5. A gene is the polynucleotide sequence with information for making one polypeptide. Each codon—a triplet of bases in DNA or RNA—codes for one amino acid. Transcription occurs when RNA polymerase produces RNA using one strand of DNA as a template. In prokaryotic cells, the RNA transcript may immediately serve as mRNA. In eukaryotic cells, the RNA is processed: A cap and tail are added, and RNA splicing removes introns and links exons together to form a continuous coding sequence. A ribosome is the site of translation, or polypeptide synthesis, and tRNA molecules serve as interpreters of the genetic code. Each folded tRNA molecule has an amino acid attached at one end and a three-base anticodon at the other end. Beginning at the start codon, mRNA is moved relative to the ribosome a codon at a time. A tRNA with a complementary anticodon pairs with each codon, adding its amino acid to the polypeptide chain. The amino acids are linked by peptide bonds. Translation stops at a stop codon, and the finished polypeptide is released. The polypeptide folds to form a functional protein, sometimes in combination with other polypeptides.

6.



Chapter 10

1. a. epithelial tissue; b. connective tissue; c. smooth muscle tissue; d. connective tissue; e. epithelial tissue

The structure of the specialized cells in each type of tissue fits their function. For example, columnar epithelial cells are specialized for absorption and secretion; the fibers and cells of connective tissue provide support and connect the tissues. The hierarchy from cell to tissue to organ is evident

in this diagram. The functional properties of a tissue or organ emerge from the structural organization and coordination of its component parts. The many projections of the lining of the small intestine greatly increase the surface area for absorption of nutrients.

2. c 3. e 4. d 5. c 6. a 7. d 8. a 9. c 10. b 11. d 12. b
13. Stratified squamous epithelium consists of many cell layers. The outer cells are flattened, filled with the protein keratin, and dead, providing a protective, waterproof covering for the body. Neurons are cells with long extensions that conduct signals to other cells, making multiple connections in the brain. Simple squamous epithelium is a single, thin layer of cells that allows for diffusion of gases across the lining of the lung. Bone cells are surrounded by a matrix that consists of fibers and mineral salts, forming a hard protective covering around the brain.
14. Extensive exchange surfaces are often located within the body. The surfaces of the intestine, urinary system, and lungs are highly folded and divided, increasing their surface area for exchange. These surfaces interface with many blood capillaries. Not all animals have such extensive exchange surfaces. Animals with small, simple bodies or thin, flat bodies have a greater surface-to-volume ratio, and their cells are closer to the surface, enabling direct exchange between cells and the outside environment.
15. The ice water would cool the blood in your head, which would then circulate throughout your body. This effect would accelerate the return to a normal body temperature. If, however, the ice water cooled the blood vessel that supplies the thermostat in your brain so that it sensed a decrease in temperature, this control center would respond by inhibiting sweating and constricting blood vessels in the skin, thereby slowing the cooling of your body.

Chapter 11

1. a. oral cavity—ingests and chews food; b. salivary glands—produce saliva; c. liver—produces bile and processes nutrient-laden blood from intestines; d. gallbladder—stores bile; e. pancreas—produces digestive enzymes and bicarbonate; f. rectum—stores feces before elimination; g. pharynx—site of openings into esophagus and trachea; h. esophagus—transports bolus to stomach by peristalsis; i. stomach—stores food, mixes food with acid, begins digestion of proteins; j. small intestine—digestion and absorption; k. large intestine—absorbs water, compacts feces; l. anus—eliminates feces
2. a. fuel, chemical energy; b. raw materials, monomers; c. essential nutrients; d. overnutrition or obesity; e. vitamins and minerals; f. essential amino acids; g. malnutrition
3. e 4. b 5. d 6. e

Chapter 12

1. a. respiratory surface; b. circulatory system; c. lungs; d. hemoglobin; e. cellular respiration; f. negative pressure breathing; g. O_2
2. a. nasal cavity; b. pharynx; c. larynx; d. trachea; e. right lung; f. bronchus; g. bronchiole; h. diaphragm
3. c 4. b 5. d 6. a 7. e 8. d 9. c
10. Advantages of breathing air: It has a higher concentration of O_2 than water and is easier to move over the respiratory surface. Disadvantage of breathing air: Living cells on the respiratory surface must remain moist, but breathing air dries out this surface.
11. Nasal cavity, pharynx, larynx, trachea, bronchus, bronchiole, alveolus, through wall of alveolus into blood vessel, blood plasma, into red blood cell, attaches to hemoglobin, carried by blood through heart, blood vessel in muscle, dropped off by hemoglobin, out of red blood cell, into blood plasma, through capillary wall, through interstitial fluid, and into muscle cell.
12. Both these effects of carbon monoxide interfere with cellular respiration and the production of ATP. By binding more tightly to hemoglobin, CO would decrease the amount of O_2 picked up in the lungs and delivered to body cells. Without sufficient O_2 to act as the final electron acceptor, cellular respiration would slow. And by blocking electron flow in the electron transport chain, cellular respiration and ATP production would cease. Without ATP, cellular work stops and cells and organisms die.
13. Llama hemoglobin has a higher affinity for O_2 than does human hemoglobin. The dissociation curve shows that its hemoglobin becomes saturated with O_2 at the lower P_{O_2} of the high altitudes to which llamas are adapted. At that P_{O_2}, human hemoglobin is only 80% saturated.

Chapter 13

1. a. capillaries of head, chest, and arms; b. aorta; c. pulmonary artery; d. capillaries of left lung; e. pulmonary vein; f. left atrium; g. left ventricle; h. aorta; i. capillaries of abdominal region and legs; j. inferior vena cava; k. right ventricle; l. right atrium; m. pulmonary vein; n. capillaries of right lung; o. pulmonary artery; p. superior vena cava

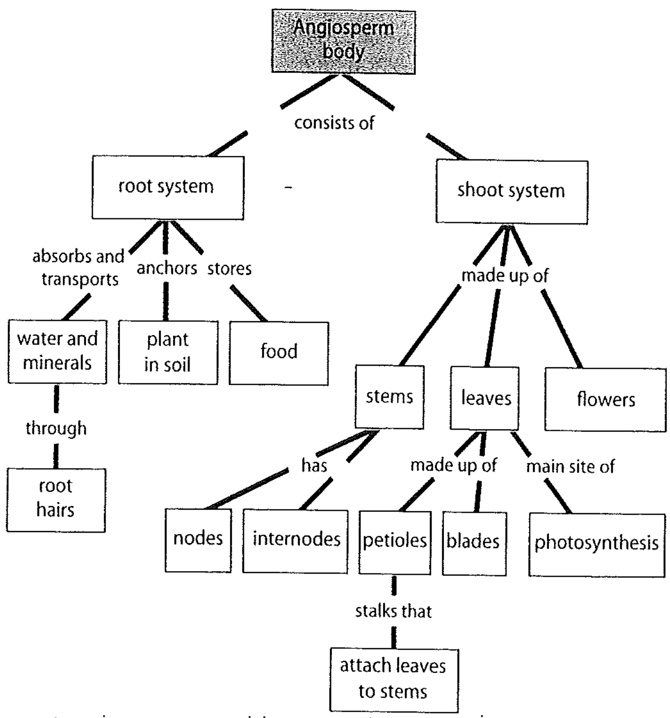
   See text Figure 13.2A for numbers and red vessels that carry oxygen-rich blood.
3. c 4. c 5. e 6. b
7. Pulmonary vein, left atrium, left ventricle, aorta, artery, arteriole, body tissue capillary bed, venule, vein, vena cava, right atrium, right ventricle, pulmonary artery, capillary bed in lung, pulmonary vein.

Chapter 14

1. c 2. c (The outer layer in a gastrula is the ectoderm; of the choices given, only the brain develops from ectoderm.) 3. a 4. e 5. g 6. d 7. h 8. f 9. a 10. b 11. c
12. Both produce haploid gametes. Spermatogenesis produces four small sperm; oogenesis produces one large egg. In humans, the ovary contains all the primary oocytes at birth, while testes can keep making primary spermatocytes throughout life. Oogenesis is not complete until fertilization, but sperm mature without eggs.

Chapter 15

1. Here is one possible concept map:



2. d (The vascular cambium forms to the outside of the primary xylem. The secondary xylem forms between primary xylem and the vascular cambium. The secondary phloem and primary phloem are outside the vascular cambium.) 3. b 4. e 5. e 6. f 7. b 8. e 9. a 10. c 11. d

12. Pollen is deposited on the stigma of a carpel, and a pollen tube grows to the ovary at the base of the carpel. Sperm travel down the pollen tube and fertilize egg cells in ovules. The ovules grow into seeds, and the ovary grows into the flesh of the fruit. As the seeds mature, the fruit ripens and falls (or is picked).
13. Celery stalk: leaf stalk (petiole); peanut: seed (ovule); strawberry: fruit (ripened ovary); lettuce: leaf blades; beet: root

Chapter 16

1. a. roots; b. xylem; c. sugar source; d. phloem; e. transpiration; f. sugar sink
2. d 3. d 4. e
5. Hypothesis: The hydrogen ions in acid precipitation displace positively charged nutrient ions from negatively charged clay particles. Test: In the laboratory, place equal amounts and types of soil in separate filters. The pore size of the filter must not allow any undissolved soil particles to pass through. Spray (to simulate rain) soil samples in the filters with solutions of different pH (for example, pH 5, 6, 7, 8, 9). Determine the concentration of nutrient ions in the solutions. (The only variable in the solutions should be the hydrogen ion concentration. Ideally, the solutions would contain no dissolved nutrient ions.) Collect fluid that drips through soil samples and filters. Determine the hydrogen ion concentration and the nutrient ion concentration in each sample of fluid. Prediction: If the hypothesis is correct, the fluid collected from the soil samples exposed to pH lower than 5.6 (acid rain) will contain the highest concentration of positively charged nutrient ions.
6. Hypothesis: When fixed nitrogen levels increase to a certain level in the soil, it slows the metabolism of (or otherwise harms or kills) the nitrogen-fixing bacteria that provide usable nitrogen to the crops. Test: Expose cultures of nitrogen-fixing bacteria (symbiotic and nonsymbiotic ones found in soil) to solutions of different concentrations of fixed nitrogen (that is, NO_3^- and NH_4^+). Determine the concentrations of nitrogen-fixing enzymes produced by the surviving bacteria in each sample. Prediction: If your hypothesis is correct and the fixed nitrogen concentration is high enough to cause harm in some of the samples, you would expect the enzyme concentration to be measurably lower in samples whose fixed nitrogen concentration is above the level that causes harm.

Glossary

A

absorption The uptake of small nutrient molecules by an organism's own body; the third main stage of food processing, following digestion.

الامتصاص امتصاص جزئيات مغذية صغيرة عن طريق جسم الكائن الحي؛ المرحلة الرئيسية الثالثة في التمثيل الغذائي والتي تأتي عقب الهضم.

acid A substance that increases the hydrogen ion (H^+) concentration in a solution.

الحمض مادة تزيد من تركيز أيون الهيدروجين (H^+) في محلول.

acid precipitation Rain, snow, or fog that is more acidic than pH 5.2.

ترسب الأحماض الأمطار أو الجليد أو الضباب الذي تتجاوز حموضته حموضة p.H 5.2.

acrosome (ak′-ruh-som) A membrane-enclosed sac at the tip of a sperm. The acrosome contains enzymes that help the sperm penetrate an egg.

الجسيم الطرفي كيس مغلف بغشاء في طرف الحيوان المنوي. يحتوي الجسيم الطرفي على إنزيمات تساعد الحيوان المنوي على اختراق البويضة.

actin A globular protein that links into chains, two of which twist helically around each other, forming microfilaments in muscle cells.

أكتين بروتين كروي متصل بسلاسل، اثنتان منها تلتفان بشكل هلالي حول بعضهم بعضًا، مكونين من خيوط دقيقة في الخلايا العضلية.

activation energy The amount of energy that reactants must absorb before a chemical reaction will start.

طاقة التنشيط كمية الطاقة التي يجب أن تمتصها المتفاعلات قبل بدء التفاعل الكيميائي.

active transport The movement of a substance across a biological membrane against its concentration gradient, aided by specific transport proteins and requiring an input of energy (often as ATP).

النقل النشط حركة المواد خلال الغشاء الحيوي حسب مدروج التركيز بمساعدة بروتينات نقل محددة مما يتطلب طاقة. (غالبا مثل ATP).

adaptation An inherited characteristic that enhances an organism's ability to survive and reproduce in a particular environment.

التكيف خاصية وراثية تعمل على تحسين قدرة الكائن الحي على العيش والتوالد في بيئة معينة.

adenine (A) (ad′-uh-nēn) A double-ring nitrogenous base found in DNA and RNA.

الأدينين (A) قاعدة نيتروجينية مزدوجة الحلقات توجد في الدنا والرنا.

adhesion The attraction between different kinds of molecules.

الالتصاق الانجذاب بين أنواع مختلفة من الجزيئات.

adipose tissue A type of connective tissue whose cells contain fat.

الأنسجة الدهنية نوع من الانسجة الضامة التي تحتوى خلاياها على دهون.

alcohol fermentation Glycolysis followed by the reduction of pyruvate to ethyl alcohol, regenerating NAD^+ and releasing carbon dioxide.

تعفن الكحوليات تحلل يتبعه انخفاض البيروفات لكحول الإيثيل، مما يساعد إلى إعادة إنتاج الدنا وانبعاث ثاني أكسيد الكربون.

alimentary canal (al′-uh-men′-tuh-rē) A complete digestive tract consisting of a tube running between a mouth and an anus.

القناة الغذائية سبيل هضمي كامل يتكون من قناة تصل بين الفم وفتحة الشرج.

allele (uh-lē′-ul) An alternative version of a gene.

أليل إصدار بديل من الجين.

allergen (al′-er-jen) An antigen that causes an allergy.

الحساسية مستضد يسبب الحساسية.

allergy A disorder of the immune system caused by an abnormally high sensitivity to an antigen. Symptoms are triggered by histamines released from mast cells.

الحساسية خلل في نظام المناعة يحدث بسبب حساسية عالية غير عادية للمستضد. تبدأ الأعراض من خلال هيستامين ينبعث من الخلايا البدينة.

alveolus (al-vē′-oh-lus) (plural, **alveoli**) One of the dead-end air sacs within the mammalian lung where gas exchange occurs.

حجيرة هوائية في الرئة(الجمع، حجيرات هوائية) أحد الأكياس الهوائية المغلقة الموجودة في رئه الثدييات حيث يحدث داخلها تبادل الهواء.

amino acid (uh-mēn′-o) An organic molecule containing a carboxyl group and an amino group; serves as the monomer of proteins.

الحمض الأميني جزيء عضوي يحتوي على مجموعة الكربوكسيل ومجموعة الأمينو؛ تعمل كمونومر للبروتينات.

amino group A chemical group consisting of a nitrogen atom bonded to two hydrogen atoms.

مجموعة الأمين مجموع كيميائية تتألف من ذرة نيتروجين متحدة مع ذرتين هيدروجين.

ammonia NH_3; A small and very toxic nitrogenous waste produced by metabolism.

النشادر NH_3؛ فضلات نيتروجينية صغيرة وسامة جدا يتم انتاجها عن طريق الأيض.

amniotic egg (am′-nē-ot′-ik) A shelled egg in which an embryo develops within a fluid-filled amniotic sac and is nourished by yolk. Produced by reptiles (including birds) and egg-laying mammals, the amniotic egg enables them to complete their life cycles on dry land.

البيضة المحيطة بالجنين بيضة ذات غلاف ينمو داخلها الجنين في كيس للجنين مليء بالسوائل تتغذى عن طريق الزلال. يتم إنتاجها عن طريق الزواحف (بما في ذلك الطيور) والثدييات التي تضع البيض، تمكنهم البيضة المحيطة بالجنين من استكمال دورة حياتهم على الأرض الجافة.

amygdala (uh-mig′-duh-la) An integrative center of the cerebrum; functionally, the part of the limbic system that seems central in recognizing the emotional content of facial expressions and laying down emotional memories.

اللوزة مركز تكاملي للمخ؛ وظيفيا، هو عبارة عن جزء من النظام الحوفي الذي يبدو مركزيا في التعرف على المحتوى الانفعالي لتعبيرات الوجه والاحتفاظ بالذكريات العاطفية.

anaphase The fourth stage of mitosis, beginning when sister chromatids separate from each other and ending when a complete set of daughter chromosomes arrives at each of the two poles of the cell.

طور الصعود المرحلة الرابعة من التفتل والتي تبدأ عندما تنفصل الكروماتيدات الشقيقة عن بعضها البعض وتنتهي عندما تصل الكروموسومات الوليدة إلى أي من قطبي الخلية.

anatomy The study of the structures of an organism.

التشريح دراسة بناء الكائن الحي.

androgen (an′-drō-jen) A steroid sex hormone secreted by the gonads that promotes the development and maintenance of the male reproductive system and male body features.

منشط الذكورة هرمون ذكورة ستيرويدي يفرز عن طريق الغدد التناسلية التي تساعد على نمو نظام الخصوبة لدى الرجال والحفاظ عليه وكذلك معالم الجسد عند الرجال.

anemia (uh-nē′-me-ah) A condition in which an abnormally low amount of hemoglobin or a low number of red blood cells results in the body cells receiving too little oxygen.

الأنيميا حالة تسبب فيها نقص كميات الهيموجلوبين بطريقة غير عادية أو نقص عدد خلايا الدم الحمراء إلى وصول القليل من الأوكسجين في خلايا الجسم.

anterior Pertaining to the front, or head, of a bilaterally symmetric animal.

أمامي يخص الجزء الأمامي أو مقدمة الحيوان الثنائي المتماثل.

anther A sac located at the tip of a flower's stamen; contains male sporangia in which meiosis occurs to produce spores that form the male gametophytes, or pollen grains.

المئبر كيس يقع في طرف سداة الزهرة؛ يحتوي على مباغات ذكورية يحدث فيه الانتصاف لإنتاج الأبواغ التي تشكل منشئات الأمشاج الذكورية أو حبوب اللقاح.

antibody (an′-tih-bod′-ē) A protein dissolved in blood plasma that attaches to a specific kind of antigen and helps counter its effects.

الأجسام المضادة بروتين يذوب في بلازما الدم والتي تجذب نوع خاص من المولدات المضادة ويساعد على الحد من تأثيرها.

anticodon (an′-tī-ko′-don) On a tRNA molecule, a specific sequence of three nucleotides that is complementary to a codon triplet on mRNA.

مقابلة الرامزة في جزيءtRNA، تسلسل خاص من ثلاث نوكليوتيدات تتكامل مع كودون ثلاثي على mRNA.

antigen (an′-tuh-jen) A foreign (nonself) molecule that elicits an adaptive immune response.

مستضد جزيء غريب (غير ذاتي) يصدر استجابة مناعية تكيفية.

anus The opening through which undigested materials are expelled.

الشرج فتحة تخرج من خلالها المواد غير المهضومة.

aorta (ā-or′-tuh) A large artery that conveys blood directly from the left ventricle of the heart to other arteries.

الوتين شريان كبير ينقل الدم مباشرة من البطين الأيسر للقلب إلى باقي الشرايين.

apical dominance (ā′-pik-ul) In a plant, the hormonal inhibition of axillary buds by a terminal bud.

هيمنة قمي في النبات، التثبيط الهرموني للبراعم الإبطية من خلال برعم طرفي.

aquaporin A transport protein in the plasma membrane of some plant or animal cells that facilitates the diffusion of water across the membrane (osmosis).

أكوابورين بروتين متنقل في الغشاء البلازمي لخلايا بعض النباتات أو الحيوانات والذي يسهل انتقال الماء عبر الغشاء (تناضح).

aqueous solution (ā′-kwā-us) A solution in which water is the solvent.

محلول مائي محلول يكون الماء فيه هو المذيب.

Archaea (ar′-kē-uh) One of two prokaryotic domains of life, the other being Bacteria.

العتيقة أحد نوعين من مجالات حياة بدائية النواه، الأخرى تسمى البكتيريا.

arteriole (ar-ter′-ē-ol) A vessel that conveys blood between an artery and a capillary bed.

الشرين وعاء ينقل الدم بين الشريان والشبكة الشعرية.

artery A vessel that carries blood away from the heart to other parts of the body.

الشريان وعاء ينقل الدم من القلب إلى الأجزاء الأخرى من الجسم.

asexual reproduction The creation of genetically identical offspring by a single parent, without the participation of sperm and egg.

التكاثر اللاجنسي إنشاء سلالة متطابقة وراثيا من خلال أب واحد، دون تدخل الحيوان المنوي والبيضة.

atom The smallest unit of matter that retains the properties of an element.

الذرة أصغر وحدة من المادة التي تحتوي على خواص العنصر.

atomic mass The total mass of an atom; also called atomic weight. Given as a whole number, the atomic mass approximately equals the mass number.

الكتلة الذرية إجمالي كتلة الذرة؛ التي تسمى أيضا الوزن الذري. وبشكل عام؛ فإن الكتلة الذرية تساوي العدد الكتلي.

atomic number The number of protons in each atom of a particular element.

العدد الذري عدد البروتونات في كل ذرة في عنصر محدد.

ATP Adenosine triphosphate, the main energy source for cells.

ATP أدينوسين ثلاثي الفوسفات، مصدر الطاقة الرئيسي للخلايا.

ATP synthase A cluster of several membrane proteins that function in chemiosmosis with adjacent electron transport chains, using the energy of a hydrogen ion concentration gradient to make ATP.

سينسيز ATP كتلة من بروتينات الغشاء المتعددة التي تعمل في تناضح كيميائي مع سلاسل الإلكترون المتنقلة المتاخمة، باستخدام مدروج التركيز لأيون الهيدروجين لإنتاج ATP.

atrium (ā′-trē-um) (plural, **atria**) A heart chamber that receives blood from the veins.

الأذين (الجمع الإذينين) غرفة في القلب تتلقى الدم من الأوردة.

autosome A chromosome not directly involved in determining the sex of an organism; in mammals, for example, any chromosome other than X or Y.

صبغي جسدي كروموسوم لا يتدخل بطريقة مباشرة في تحديد نوع الكائن الحي؛ في الثدييات، على سبيل المثال، أي كروموسوم غير X أو Y.

autotroph (ot′-ō-trōf) An organism that makes its own food (often by photosynthesis), thereby sustaining itself without eating other organisms or their molecules. Plants, algae, and numerous bacteria are autotrophs.

ذاتي التغذي كائن حي يصنع طعامه بنفسه (غالبا من خلال التمثيل الضوئي)، ومن ثم يكفي نفسه دون أكل أي كائنات حية أخرى أو الجزيئات الخاصة بها. النباتات والطحالب وأنواع متعددة من البكتيريا تعتبر ذاتية التغذي.

auxin (ok′-sin) A plant hormone (indoleacetic acid or a related compound) whose chief effect is to promote seedling elongation.

الأوكسين هرمون نباتي (حمض الأسيتيك أو مركب ذو صلة) يكون تأثيره الرئيسي هو استطالة النبتة.

axillary bud (ak′-sil-ār-ē) An embryonic shoot present in the angle formed by a leaf and stem.

البراعم الإبطية سويقة جنينية موجودة في زاوية النبات تتشكل عن طريق الورقة والساق.

B

B cell A type of lymphocyte that matures in the bone marrow and later produces antibodies. B cells are responsible for the humoral immune response.

نوع B خلية من اللّمفاويَّات ينضج في نخاع العظام ويُنتج بعد ذلك أجسام مضادة. خلايا B مسؤولة عن الاستجابة المناعية الخِلطيَّة.

bacillus (buh-sil′-us) (plural, **bacilli**) A rod-shaped prokaryotic cell.

البكتريا العصوية خلية بدائية النواة على شكل قضيب.

Bacteria One of two prokaryotic domains of life, the other being Archaea.

البكتريا إحدى دورات حياة الخلية بدائية النواة والدورة الأخرى هي الجراثيم العتيقة

bacteriophage (bak-tēr′-ē-ō-fāj) A virus that infects bacteria; also called a phage.

عاثية فيروس يصيب البكتيريا؛ يسمى أيضا الفج.

basal metabolic rate (BMR) The number of kilocalories a resting animal requires to fuel its essential body processes for a given time.

معدل الاستقلاب الأساسي (BMR) عدد كيلوات السعرات الحرارية الذي يحتاجه الحيوان المسترخي لتزويد عمليات جسمه الأساسية بالطاقة لفترة معينة من الوقت.

base A substance that decreases the hydrogen ion (H^+) concentration in a solution.

القاعدة مادة تقلل تركيز الأيون الهيدروجيني (H^+) في المحلول.

behavior Individually, an action carried out by the muscles or glands under control of the nervous system in response to a stimulus; collectively, the sum of an animal's responses to external and internal stimuli.

السلوك بشكل منفصل هو عبارة عن إجراء تقوم به العضلات أو الغدد يتحكم فيه الجهاز العصبي استجابة إلى منبه معين؛ جماعيا، مجموع استجابات الحيوان للمحفزات الخارجية والداخلية.

bilateral symmetry An arrangement of body parts such that an organism can be divided equally by a single cut passing longitudinally through it. A bilaterally symmetric organism has mirrorimage right and left sides.

تطابق ثنائي ترتيب لأجزاء الجسم يستطيع من خلالها الكائن الحي الانقسام بصورة متساوية عن طريق قطع فردي يمر طوليا خلاله. الكائنات الحية المتطابقة ثنائيا تحتوي على صورة متطابقة للأجزاء اليمني واليسرى.

binary fission A means of asexual reproduction in which a parent organism, often a single cell, divides into two genetically identical individuals of about equal size.

انشطار ثنائي وسيلة للتوالد اللا جنسي، ينقسم فيه الكائن الحي الأب، غالبا خلية مفردة، إلى كائنين متماثلين وراثيا بحجم متساوي تقريبا.

binomial A two-part, latinized name of a species; for example, *Homo sapiens*.

ثنائي الحدود اسم لاتيني مكون من جزئين؛ على سبيل المثال الإنسان العاقل.

birds Members of a clade of reptiles that have feathers and adaptations for flight.

الطيور أعضاء الفصيلة في متعددة الأفرع للزواحف بها ريش وتتمتع بقدرة على الطيران.

blastocoel (blas′-tuh-sēl) In a developing animal, a central, fluidfilled cavity in a blastula.

جوف الأريمة في الحيوان النامي، جوف مركزي مليء بالسوائل في الأريمة.

blastula (blas′-tyū-luh) An embryonic stage that marks the end of cleavage during animal development; a hollow ball of cells in many species.

الأريمة مرحلة جنينية تحدد نهاية التشطر أثناء نمو الحيوان؛ كرة مجوفة من الخلايا في العديد من الأنواع.

blood A type of connective tissue with a fluid matrix called plasma in which red blood cells, white blood cells, and platelets are suspended.

الدم نوع من الأنسجة الضامة بها مصفوفة من السوائل تسمى البلازما تتعلق بها خلايا الدم الحمراء وخلايا الدم البيضاء وصفيحات الدم.

blood-brain barrier A system of capillaries in the brain that restricts passage of most substances into the brain, thereby preventing large fluctuations in the brain's environment.

الحائل الدموي الدماغي مجموعة من الشعيرات في المخ تقود مرور معظم المواد إلى المخ، ومن ثم منع حدوث تقلبات كبيرة في بيئة المخ.

body cavity A fluid-containing space between the digestive tract and the body wall.

تجويف الجسم مكان يحتوي على سوائل بين السبيل الهضمي وجدار الجسم.

bolus A lubricated ball of chewed food.

كرة مشحمة من الأطعمة الممضوغة.

bone A type of connective tissue consisting of living cells held in a rigid matrix of collagen fibers embedded in calcium salts.

العظام نوع من الأنسجة الضامة المؤلفة من خلايا حية تصطف في مصفوفة صلبة من ألياف الكولاجين تتخللها أملاح الكالسيوم.

brain The master control center of the nervous system, involved in regulating and controlling body activity and interpreting information from the senses transmitted through the nervous system.

المخ مركز التحكم الرئيسي للنظام العصبي، يدخل في تنظيم نشاط الجسم والتحكم فيه وترجمة المعلومات من الحواس المنقولة عبر النظام العصبي.

brainstem A functional unit of the vertebrate brain, composed of the midbrain, the medulla oblongata, and the pons; serves mainly as a sensory filter, selecting which information reaches higher brain centers.

جذع الدماغ وحدة وظيفية للدماغ الفقاري، مؤلفة من الدماغ المتوسط والبصلة والجسر؛ تعمل بصورة رئيسية كمرشح حسي، لاختيار المعلومات التي تصل إلى مراكز المخ العليا.

breathing Ventilation of the lungs through alternating inhalation and exhalation.

التنفس تهوية الرئة من خلال عمليتي الشهيق والزفير المتبادلتين.

breathing control center The part of the medulla in the brain that directs the activity of organs involved in breathing.

مركز التحكم في التنفس جزء من الألباب في المخ يقوم بتوجيه نشاط الأعضاء التي تدخل في عملية التنفس.

bronchiole (bron′-kē-ōl) A fine branch of the bronchi that transports air to alveoli.

الشعيبة فرع رفيع من الشعب الهوائية التي تحمل الهواء إلى الحويصلات الهوائية.

bronchus (bron′-kus) (plural, **bronchi**) One of a pair of breathing tubes that branch from the trachea into the lungs.

القصبة الهوائية (الجمع، قصبات هوائية) واحد من زوج من أنابيب التنفس التي تتفرع من الرغامي إلى الرئة.

budding A means of asexual reproduction whereby a new individual develops from an outgrowth of a parent. The new individual eventually splits off and lives independently.

تبرعم وسيلة للتوالد اللاجنسي حيث يتطور أحد الأفراد الجديدة من انتبات الأب. ينفصل الفرد الجديد ويعيش مستقلا.

buffer A chemical substance that resists changes in pH by accepting hydrogen ions from or donating hydrogen ions to solutions.

دراثة مادة كيميائية تقاوم التغير في pH عن طريق قبول أيونات الهيدروجين من أو إلى المحلول.

bulbourethral gland (bul′-bō-yū-rē′-thrul) One of a pair of glands near the base of the penis in the human male that secrete a clear alkaline mucus.

الغدة الإحليلية واحد من زوج من الغدد بالقرب من قاعدة القضيب في العضو الذكري البشري والذي يفرز مخاطا قلويًا.

bulk feeder An animal that eats relatively large pieces of food.

متغذ على كميات كبيرة حيوان يأكل كميات كبيرة نسبيا من الطعام.

C

calcitonin (kal′-sih-tōn′-in) A peptide hormone secreted by the thyroid gland that lowers the blood calcium level.

كالسيتونين هرمون الببتيد الذي يفرز عن طريق الغدة الدرقية التي تقلل مستويات الكالسيوم في الدم.

Calvin cycle The second of two stages of photosynthesis; a cyclic series of chemical reactions that occur in the stroma of a chloroplast, using the carbon in CO_2 and the ATP and NADPH produced by the light reactions to make the energy-rich sugar molecule G3P.

دورة كالفين ثاني مرحلتين من التمثيل الغذائي؛ سلسلة دورية من التفاعلات الكيميائية التي تحدث في ستروما البلاستيدات الخضراء، باستخدام الكربون في ثاني أكسيد الكربون وأيموسين ثلاثي الفوسفات و NADPH التي تتم من خلال التفاعلات الضوئية التي تكون جزئ السكر G3P الغني بالطاقة.

CAM plant A plant that uses an adaptation for photosynthesis in arid conditions in which carbon dioxide entering open stomata during the night is converted to organic acids, which release CO_2 for the Calvin cycle during the day, when stomata are closed.

نبات CAM نبات يستخدم التكيف على التمثيل الضوئي في الظروف القاحلة التي يتحول فيها ثاني أكسيد الكربون الذي يدخل عبر الفوهات المفتوحة أثناء الليل إلى أحماض عضوية، والتي تبعث ثاني أكسيد الكربون لدورة كالفين أثناء النهار، عندما تكون الفوهات مغلقة.

cancer A disease characterized by the presence of malignant tumors (rapidly growing and spreading masses of abnormal body cells) in the body.
السرطان مرض يتميز بوجود أورام خبيثة (كميات هائلة من خلايا الجسم غير العادية التي تنمو وتنتشر بسرعة فائقة) في الجسم.

capillary (kap′-il-er-ē) A microscopic blood vessel that conveys blood between an arteriole and a venule; enables the exchange of nutrients and dissolved gases between the blood and interstitial fluid.
الشعيرة وعاء دموي دقيق ينقل الدم بين الشرين والوريد ويسمح بتبادل المواد الغذائية والغازات الذائبة بين الدم والسائل الخلالي.

capillary bed A network of capillaries in a tissue or organ.
الشبكة الشعرية شبكة من الأوعية الموجودة في أحد الأنسجة أو الأعضاء.

capsid The protein shell that encloses a viral genome.
قفيصة قشرة البروتين التي تغلف الجينوم الفيروسي.

carbohydrate (kar′-bō-hi′-drāt) Member of the class of biological molecules consisting of single-monomer sugars (monosaccharides), two-monomer sugars (disaccharides), and polymers (polysaccharides).
الكربوهيدرات عضو في فئة الجزيئات الحيوية التي تتألف من السكريات أحادية المونومر (أحادي السكاريد)، والسكريات ثنائية المونومر (السكاريد)، والبلمرات (السكاريد المتعددة).

carbon fixation The incorporation of carbon from atmospheric CO_2 into the carbon in organic compounds. During photosynthesis in a C_3 plant, carbon is fixed into a three-carbon sugar as it enters the Calvin cycle. In C_4 and CAM plants, carbon is fixed into a four-carbon sugar.
تثبيت الكربون دمج الكربون من ثاني أكسيد الكربون الموجود في الجو إلى الكربون الموجود في المركبات العضوية. أثناء التمثيل الضوئي في نبات C3، يتم تثبيت الكربون في السكر ثلاثي الكربون تماما كما يدخل دورة كالفين. في نباتات C4 وCAM يتم تثبيت الكربون في السكر رباعي الكربون.

carbon skeleton The chain of carbon atoms that forms the structural backbone of an organic molecule.
هيكل الكربون سلسلة ذرات الكربون التي تشكل العمود الفقري الأساس للجزيء العضوي.

carbonyl group (kar′-buh-nēl′) A chemical group consisting of a carbon atom linked by a double bond to an oxygen atom.
مجموعة الكربونيل مجموعة كيميائية تتكون من ذرة كربون ترتبط برابط مزدوج مع ذرة أكسجين.

carboxyl group (kar′-bok-sil) A chemical group consisting of a carbon atom double-bonded to an oxygen atom and also bonded to a hydroxyl group.
مجموعة الكربوكسيل مجموعة كيميائية تتكون من ذرة كربون ترتبط برابط مزدوج مع ذرة أكسجين وترتبط أيضا بمجموعة الكربوكسيل.

carcinogen (kar-sin′-uh-jin) A cancer-causing agent, either highenergy radiation (such as X-rays or UV light) or a chemical.
مسرطن عنصر مسبب للسرطان، إما إشعاع ذو طاقة عالية (مثل أشعة أكس أو الأشعة فوق البنفسجية) أو مادة كيميائية.

cardiac cycle (kar′-dē-ak) The alternating contractions and relaxations of the heart.
الدورة القلبية الانقباضات والانبساطات المتبادلة للقلب.

cardiac muscle A type of striated muscle that forms the contractilewall of the heart.
عضلة القلب نوع من العضلات الهيكلية التي تكون الجدار النابض للقلب.

cardiac output The volume of blood pumped per minute by each ventricle of the heart.
النتاج القلبي كمية الدم التي يتم ضخها كل دقيقة من كل بطين في القلب.

cardiovascular system A closed circulatory system with a heart and a branching network of arteries, capillaries, and veins.
الجهاز القلبي الوعائي نظام دوراني مغلق به القلب وشبكة متفرعة من الشرايين والشعيرات والأوردة.

carnivore An animal that mainly eats other animals.
لاحم الحيوانات التي تتغذى على حيوانات أخرى.

carpel (kar′-pul) The female part of a flower, consisting of a stalk with an ovary at the base and a stigma, which traps pollen, at the tip.
خباء جزء مؤنث من الزهرة، يتكون من سويقة بمبيض في القاعدة ووصمة والتي تصطاد حبات اللقاح، في طرف الزهرة.

carrier An individual who is heterozygous for a recessively inherited disorder and who therefore does not show symptoms of that disorder but who may pass on the recessive allele to offspring.
الناقل كائن متخالف بسبب خلل وراثي كبير ولا يبين أعراض ذلك الخلل ولكنه يمرر الأليل المتنح إلى السلالة.

cartilage (kar′-ti-lij) A flexible connective tissue consisting of living cells and collagenous fibers embedded in a rubbery matrix.
الغضروف نسيج مرن موصل يتكون من خلايا حية وألياف كولاجينية موجودة في مصفوفة مطاطية.

cation exchange A process in which positively charged minerals are made available to a plant when hydrogen ions in the soil displace mineral ions from the clay particles.
تبادل الكاتيون عملية يتم فيها توفير معادن مشحونة إيجابيا للنبات عندما تقوم أيونات الهيدروجين في التربة بإزاحة أيونات المعادن من جسيمات الطين.

cell A basic unit of matter separated from its environment by a plasma membrane; the fundamental structural unit of life.
الخلية وحدة اساسية من مواد حيه تنفصل عن البيئة الخارجية بغشاء بلازمي وهى الوحدة البنائية الأساسية للحياة.

cell body The part of a cell, such as a neuron, that houses the nucleus.
جسم الخلية جزء من الخلية مثل العصب الذى يسكن النواة.

cell cycle An ordered sequence of events (including interphase and the mitotic phase) that extends from the time a eukaryotic cell is first formed from a dividing parent cell until its own division into two cells.
دورة الخلية سلسلة من الأحداث المنظمة (تتضمن الطور البيني والتفتلي) التي تمتد من بدء الخلية الحيوانية في الانقسام من الخلية الأم وحتى انقسامها بنفسها الى خليتين.

cell division The reproduction of a cell through duplication of the genome and division of the cytoplasm.
انقسام الخلية هو تكاثر الخلية عن طريق تكرار الجينوم وانقسام السيتوبلازم.

cell theory The theory that all living things are composed of cells and that all cells come from other cells.
النظرية الخلوية هي نظرية تفيد بأن كل الكائنات الحية تتكون من خلايا وكل هذه الخلايا تأتي من خلايا أخرى.

cell wall A protective layer external to the plasma membrane in plant cells, bacteria, fungi, and some protists; protects the cell and helps maintain its shape.
جدار الخلية طبقة خارجية حامية لغشاء الخلية النباتية والبكتيرية والفطرية وبعض الأولانيات وهو يحمي الخلية ويساعد في الحفاظ على شكلها.

cellular metabolism (muh-tab′-uh-lizm) All the chemical activities of a cell.
الأيض الخلوي كل الأنشطة الكيميائية للخلية.

cellular respiration The aerobic harvesting of energy from food molecules; the energy-releasing chemical breakdown of food molecules, such as glucose, and the storage of potential energy in a form that cells can use to perform work; involves glycolysis, the citric acid cycle, and oxidative phosphorylation (the electron transport chain and chemiosmosis).
التنفس الخلوي الحصاد الهوائي للطاقة من جزيئات الغذاء؛ التكسر الكيميائي للجزيئات الغذائية الباعث للطاقة؛ مثل الجلوكوز وتخزين الطاقة الجهدية في صورة تستطيع الخلايا استخدامها لإجراء عملها؛ وتشتمل على تحلل السكر ودورة حمض الستريك، والفسفتة الأكسيدية (السلسلة الحاملة للإلكترون والتناضح الكيميائي).

cellulose (sel′-yū-lōs) A structural polysaccharide of plant cell walls composed of glucose monomers. Cellulose molecules are linked into cable-like fibrils.

سلولوز متعدد سكاريد بنيوي لجدران خلايا النبات مؤلف من مونومر الجلوكوز. جزيئات السلولوز مرتبطة بليفات تشبه الكابلات.

central canal The narrow cavity in the center of the spinal cord that is continuous with the fluid-filled ventricles of the brain.

القناة المركزية التجويف الضيق في مركز الحبل الشوكي والمتصل مع بطينات الدماغ المليئة بالسوائل.

central vacuole In a plant cell, a large membranous sac with diverse roles in growth and the storage of chemicals and wastes.

الفجوة المركزية في خلية النبات، كيس غشائي كبير له أدوار عديدة في النمو وتخزين المواد الكيميائية والفضلات.

centriole (sen′trē-ōl) A structure in an animal cell composed of cylinders of microtubule triplets arranged in a 9 + 0 pattern. An animal usually has a centrosome with a pair of centrioles involved in cell division.

مريكز هيكل في خلية الحيوان يتكون من أسطوانات من أنيبيبات ثلاثية مرتبة في وضع 9 + 1. الحيوان يكون عادة لديه جسيم مركزي به زوج من المريكزات مشتركة في انقسام الخلية.

centromere (sen′-trō-mēr) The region of a duplicated chromosome where two sister chromatids are joined (often appearing as a narrow "waist") and where spindle microtubules attach during mitosis and meiosis. The centromere divides at the onset of anaphase during mitosis and anaphase II during meiosis.

القسيم المركزي منطقة كروموسوم مكرر حيث يرتبط فيها شقان صبغيان (تظهر غالبا "كخصر" ضيق) حيث ترتبط الأنيبيبات المغزلية أثناء التفتل والانتصاف. ينقسم الجسيم المركزي في بداية طور الصعود في الانقسام الخلوي أثناء التفتل وطور الصعود الثاني أثناء الانتصاف.

centrosome (sen′-trō-sōm) Material in the cytoplasm of a eukaryotic cell that gives rise to microtubules; important in mitosis and meiosis; also called the microtubule-organizing center

الجسيم المركزي مادة في الهيولي للخلية حقيقية النواة التي تؤدي إلى ظهور الأنيبيبات؛ ويعد ضروري للتفتل والانتصاف؛ يسمى أيضا مركز تنظيم الأنيبيبة.

cerebral cortex (suh-rē′-brul kor′-teks) A folded sheet of gray matter forming the surface of the cerebrum. In humans, it contains integrating centers for higher brain functions such as reasoning, speech, language, and imagination.

قشرة المخ صحيفة مطوية من مادة رمادية والتي تشكل سطح الدماغ. في البشر، يحتوي على مراكز متكاملة لوظائف أعلى للمخ مثل التعقل والتحدث واللغة والتخيل.

cerebral hemisphere The right or left half of the vertebrate cerebrum.

نصف الكرة المخية النصف الأيمن أو الأيسر من المخ الفقاري.

cerebrospinal fluid (suh-rē′-brō-spī′-nul) Blood-derived fluid that surrounds, nourishes, and cushions the brain and spinal cord.

السائل الدماغي النخاعي سائل مشتق من الدم يحيط ويغذي المخ والحبل الشوكي.

cerebrum (suh-rē′-brum) The largest, most sophisticated, and most dominant part of the vertebrate forebrain, made up of right and left cerebral hemispheres.

المخ أكبر الأجزاء وأكثرها تعقيدا وأكثرها سيطرة في الدماغ المقدم الفقاري، مكون من نصف الكرة المخية الأيمن والأيسر.

cervix (ser′-viks) The neck of the uterus, which opens into the vagina.

عنق الرحم عنق الرحم والذي يفتح في المهبل.

character A heritable feature that varies among individuals within a population, such as flower color in pea plants or eye color in humans.

الخاصية ميزة وراثية تختلف بين الأفراد في العينة، مثل لون الزهرة أو نباتات البازيلاء ولون العيون في البشر.

chemical bond An attraction between two atoms resulting from a sharing of outer-shell electrons or the presence of opposite charges on the atoms. The bonded atoms gain complete outer electron shells

الرابط الكيميائي ارتباط بين ذرات تنتج عن مشاركةإلكترونات القشرة الخارجية أو وجود شحنات مضادة على الذرات. الذرات المرتبطة تحصل على قشور إلكترونات خارجية كاملة.

chemical energy Energy available in molecules for release in a chemical reaction; a form of potential energy.

الطاقة الكيميائية طاقة متوفرة في الجزيئات تصدر عند التفاعلات الكيميائية؛ شكل من الطاقة الجهدية.

chemical reaction The making and breaking of chemical bonds, leading to changes in the composition of matter.

التفاعل الكيميائي صنع وقطع الروابط الكيميائية، والتي تؤدي إلى تغيرات في تركيب المواد.

chemiosmosis (kem′-ē-oz-mō′-sis) Energy-coupling mechanism that uses the energy of hydrogen ion (H^+) gradients across membranes to drive cellular work, such as the phosphorylation of ADP; powers most ATP synthesis in cells.

تناضح كيميائي آلية مزدوجة الطاقة تستخدم مركبات طاقة أيون الهيدروجين (H^+) عبر الأغشية كي تشكل العمل الخلوي، مثل فسفتة ADP؛ والتي تدعم تخليق ATP في الخلايا.

chlorophyll A green pigment located within the chloroplasts of plants, algae, and certain prokaryotes. Chlorophyll *a* can participate directly in the light reactions, which convert solar energy to chemical energy.

الكلوروفيل صبغة خضراء تقع في البلاستيدات الخضراء في النبات والطحالب وبدائيات النواة. يستطيع كلوروفيل A المشاركة مباشرة في التفاعلات الضوئية، والذيبحول الطاقة الشمسية إلى طاقة كيميائية.

chloroplast (klō′-rō-plast) An organelle found in plants and photosynthetic protists that absorbs sunlight and uses it to drive the synthesis of organic molecules (sugars) from carbon dioxide and water.

البلاستيدات الخضراء عضيات موجودة في النباتات والأولانيات المعتمدة على التمثيل الضوئي والتي تمتص ضوء الشمس وتستخدمه لتوجه صناعة الجزيئات العضوية (السكريات) من ثانيأكسيد الكربون والماء.

cholesterol (kō-les′-tuh-rol) A steroid that is an important component of animal cell membranes and that acts as a precursor molecule for the synthesis of other steroids, such as hormones.

الكوليسترول ستيرويد يعمل كمكون هام في غشاء الخلية الحيوانية ويعمل كجزيء البداية لصناعة الستيرويدات الأخرى مثل الهرمونات.

chromatin (krō′-muh-tin) The combination of DNA and proteins that constitutes eukaryotic chromosomes; often used to refer to the diffuse, very extended form taken by chromosomes when a cell is not dividing.

الكروماتين تركيبة من الدنا والبروتينات التي تكون الكروموسومات الحيوانية والتي تشير غالبا إلى الانتشار، شكل متمدد يؤخذ من الكروموسومات في حال عدم انقسام الخلية.

chromosome (krō′-muh-sōm) A threadlike, gene-carrying structure found in the nucleus of a eukaryotic cell and most visible during mitosis and meiosis; also, the main gene-carrying structure of a prokaryotic cell. A chromosomes consists of one very long piece of chromatin, a combination of DNA and protein.

الكروموسوم بناء يشبه الخيط ويحمل الجينات، موجود في نواة الخلية الحيوانية و يرى غالبا أثناء التفتل والانتصاف؛ البناء الرئيسي الحامل للجينات للخلية بدائية النواة. يتكون الكروموسوم من قطعة طويلة للغاية من الكروماتين، تركيبة من الدنا والبروتين.

chromosome theory of inheritance A basic principle in biology stating that genes are located on chromosomes and that the behavior of chromosomes during meiosis accounts for inheritance patterns.

نظرية الوراثة في الكروموسوم مبدأ رئيسي في الأحياء يفيد بأن الجينات تقع في الكروموسومات وأن سلوك الكروموسومات أثناء الانتصاف يفسر نماذج الوراثة.

GLOSSARY

chyme (kīm) The mixture of partially digested food and digestive juices formed in the stomach.

الكيموس خليط من طعام مهضوم جزئيا عصائر مهضومة تتكون في المعدة.

cilium (plural, **cilia**) A short cellular appendage specialized for locomotion, formed from a core of nine outer doublet microtubules and two single microtubules (the 9 + 2 pattern) covered by the cell's plasma membrane.

الهدب (الجمع أهداب) زائدة خلوية قصيرة مخصصة للحركة، تتكون من مركز تسعة أنيبيات مزدوجة خارجية وأنيبيتين فرديتين (نموذج 9 + 2) مغطى بغشاء البلازما.

circulatory system The organ system that transports materials such as nutrients, O_2, and hormones to body cells and transports CO_2 and other wastes from body cells.

الجهاز الدوري نظام الأعضاء الذي ينقل المواد مثل المواد الغذائية والأكسجين والهرمونات لخلايا الجسم كما ينقل ثاني أكسيد الكربون وغيرها من الفضلات من خلايا الجسم.

citric acid cycle The chemical cycle that completes the metabolic breakdown of glucose molecules begun in glycolysis by oxidizing acetyl CoA (derived from pyruvate) to carbon dioxide. The cycle occurs in the matrix of mitochondria and supplies most of the NADH molecules that carry energy to the electron transport chains. Together with pyruvate oxidation, the second major stage of cellular respiration.

دورة حمض الستريك دورة كيميائية تكمل التكسر الأيضي لجزيئات الجلوكوز التي تبدأ في تحلل السكر عن طريق أكسدة الأسيتيل CoA (المنشق من البيروفات) إلى ثاني أكسيد الكربون. تتم تلك الدورة في مصفوفة المتقدرات وتوفر معظم جزيئات NADH التي تحمل الطاقة إلى سلاسل نقل الإلكترونات. تمثل تلك الدورة مع أكسدة البيروفات المرحلة الرئيسية الثانية في التنفس الخلوي.

clade A group of species that includes an ancestral species and all its descendants.

كليد مجموعة من الأنواع التي تشتمل على نوع موروث وجميع التابعين له.

class In Linnaean classification, the taxonomic category above order.

الفئة في: التصنيف الحيوي، الفئة التصنيفية خارج الترتيب.

cleavage (klē′-vij) (1) Cytokinesis in animal cells and in some protists, characterized by pinching in of the plasma membrane. (2) In animal development, the first major phase of embryonic development, in which rapid cell divisions without cell growth transforms the animal zygote into a ball of cells.

التشطر (1) الحرائك الخلوية في الخلايا الحيوانية وفي بعض الأولانيات، والتي تضغط على غشاء البلازما. (2) في تطور الحيوانات، المرحلة الرئيسية الأولى من تطور الجنين، والتي تقوم فيها الانقسامات السريعة للخلية دون نمو الخلايا بتحويل اللاقحة الحيوانية إلى كرة من الخلايا.

clitoris An organ in the female that engorges with blood and becomes erect during sexual arousal.

البظر عضو في الأنثى متحفل بالدم ويصبح منتصبا عند الاستثارة الجنسية.

clone As a verb, to produce genetically identical copies of a cell, organism, or DNA molecule. As a noun, the collection of cells, organisms, or molecules resulting from cloning; colloquially, a single organism that is genetically identical to another because it arose from the cloning of a somatic cell.

الاستنساخ هذا المصطلح يستخدم كفعل بمعنى انتاج نسخ متماثلة جينيا من الخلية أو الكائن الحي أو جزئ الدنا. ويستخدم كاسم، بمعنى مجموعة من الخلايا أو الكائنات الحية أو الجزيئات التي تنتج عن الاستنساخ؛ بالعامية، عبارة عن كائن حي منفرد متماثل جينيا مع كائن آخر لأنه ناتج عن الاستنساخ من خلية جسدية.

closed circulatory system A circulatory system in which blood is confined to vessels and is kept separate from the interstitial fluid.

الجهاز الدوري المغلق نظام دوري يتم فيه احتجاز الدم في أوعية ويتم فصله عن السائل الخلالي.

coccus (kok′-us) (plural, **cocci**) A spherical prokaryotic cell.

القرمزية (الجمع قرمزيات) خلية كروية بدائية النواة.

codon (ko′-don) A three-nucleotide sequence in mRNA that specifies a particular amino acid or polypeptide termination signal; the basic unit of the genetic code.

رامزة تسلسل ثلاثي النوكليوتيد في mRNA والذي يحدد حمضًا أمينيًا معينًا أو إشارة انتهاء عديد الببتيد؛ الوحدة الأساسية للرمز الجيني.

coelom (sē′-lom) A body cavity completely lined with mesoderm.

الجوف العام تجوف في الجسم متصل بصورة تامة مع الأديم المتوسط.

cognition The process carried out by an animal's nervous system that includes perceiving, storing, integrating, and using the information obtained by the animal's sensory receptors.

المعرفة العملية التي يتم تنفيذها من خلال الجهاز العصبي للحيوان والتي تشتمل على الشعور وتخزين وتفسير واستخدام المعلومات التي يتم الحصول عليها عن طريق المستقبلات الحسية للحيوان.

cohesion (kō-hē′-zhun) The sticking together of molecules of the same kind, often by hydrogen bonds.

التماسك التصاق الجزيئات من نفس النوع مع بعضها بعضها بعضًا، غالبا عن طريق روابط هيدروجينية.

collenchyma cell (kō-len′-kim-uh) In plants, a cell with a thick primary wall and no secondary wall, functioning mainly in supporting growing parts.

خلية النسيج الغروي في النباتات، هي عبارة عن خلية بجدار رئيسي سميك وليس بها جدار ثانوي، وتعمل بصورة أساسية في دعم الأجزاء النامية.

colon (kō′-lun) Large intestine; the portion of the vertebrate alimentary canal between the small intestine and the anus; functions mainly in water absorption and the formation of feces.

القولون الأمعاء الغليظة؛ جزء من القناة الهضمية الفقارية بين الأمعاء الدقيقة وفتحة الشرج؛ وتعمل بصورة رئيسية في امتصاص الماء وتكوين البراز.

communication Animal behavior including transmission of, reception of, and response to signals.

الاتصال السلوك الحيواني الذي يشتمل على إرسال واستقبال الإشارات والاستجابة لها.

companion cell In a plant, a cell connected to a sieve-tube element whose nucleus and ribosomes provide proteins for the sieve-tube element.

الخلية المرافقة في النبات، عبارة عن خلية متصلة بعنصر أنبوب منخلي توفر النواة فيه والريبوسوم بروتينات لعنصر الأنبوب المنخلي.

complete digestive tract A digestive tube with two openings, a mouth and an anus.

السبيل الهضمي الكامل أنبوب هضمي بفتحتين، الفم والشرج.

complete dominance A type of inheritance in which the phenotypes of the heterozygote and dominant homozygote are indistinguishable.

السيادة الكاملة نوع من الإرث لا يمكن فيه التمييز بين النمط الظاهري للزيجوت متغايرة الألائل والزيجوت متماثلة الألائل السائدة.

compost Decomposing organic material that can be used to add nutrients to soil.

السماد المخلط مواد عضوية مركبة يمكن استخدامها لإضافة مغذيات للتربة.

compound A substance containing two or more elements in a fixed ratio. For example, table salt (NaCl) consists of one atom of the element sodium (Na) for every atom of chlorine (Cl).

المركب مادة تحتوي على عنصرين أو أكثر بمعدلات ثابتة. على سبيل المثال، ملح الطعام (NaCl) يتكون من ذرة من عنصر الصوديوم (Na) لكل ذرة من الكلور (Cl).

concentration gradient A region along which the density of a chemical substance increases or decreases. Cells often maintain concentration gradients of ions across their membranes. When a gradient exists, substances tend to move from where they are more concentrated to where they are less concentrated.

مدروج التركيز منطقة تزيد أو تقل عندها كثافة المواد الكيميائية. تحتفظ الخلايا غالبا بمدروج تركيز للأيونات عبر الأغشية الخاصة بها. عندما يزيد المدروج، تميل المواد إلى التحرك من الأماكن التي تكون فيها أكثر تركيزا إلى الأماكن التي تكون فيها أقل تركيزا.

conception The fertilization of the egg by a sperm cell in humans.

الحمل تخصيب البيضة بخلية الحيوان المنوي في البشر.

conjugation The union (mating) of two bacterial cells or protist cells and the transfer of DNA between the two cells.

الاقتران اتحاد (تآلف) بين خليتين بكتيريتين أو خلايا وحيدة الخلية وانتقال الدنا بين الخليتين.

connective tissue Animal tissue that functions mainly to bind and support other tissues, having a sparse population of cells scattered through an extracellular matrix, which they produce.

النسيج الضام نسيج حيواني يعمل بصورة رئيسية لربط ودعم الأنسجة الأخرى والتي يكون بها عينات كثيرة من الخلايا المنتشرة في مصفوفة خارج الخلية، والتي تقوم بإنتاجها.

controlled experiment An experiment in which an experimental group is compared with a control group that varies only in the factor being tested.

تجربة ذات شواهد تجربة يتم فيها مقارنة المجموعة التجريبية بالمجموعة ذات الشواهد التي تختلف فقط في العنصر الذي يتم اختباره.

copulation Sexual intercourse, usually necessary for internal fertilization to occur.

الجماع هو التقاء جنسي، يكون عادة ضروري لحدوث التخصيب الداخلي.

cork The outermost protective layer of a plant's bark, produced by the cork cambium.

فلين الطبقة الوقائية الخارجية للحاء النبات، والتي يتم إنتاجها من خلال كامبيوم الفلين.

cork cambium Meristematic tissue that produces cork cells during secondary growth of a plant.

كامبيوم الفلين نسيج بارضي ينتج خلايا الفلين أثناء النمو الثانوي للنبات.

corpus luteum (kor′-pus lū′-tē-um) A small body of endocrine tissue that develops from an ovarian follicle after ovulation and secretes progesterone and estrogen during pregnancy.

الجسم الأصفر جسم صغير من الغدة الصماء. جسم يتطور من الجريب المبيضي بعد الإباضة ويفرز البروجستيرون والإستروجين أثناء الحمل.

cortex In plants, the ground tissue system of a root, made up mostly of parenchyma cells, which store food and absorb minerals that have passed through the epidermis.

القشرة في النباتات، نظام الأنسجة الأرضية للجذور، المصنوع غالبا من خلايا المتن، والتي تخزن الأطعمة وتمتص المعادن التي تمر خلال البشرة.

cotyledon (kot′-uh-lē′-don) The first leaf that appears on an embryo of a flowering plant; a seed leaf. Monocot embryos have one cotyledon; dicot embryos have two.

الفلقة الورقة الأولى التي تظهر في جنين النبات المزهر؛ تسمى ورقة البذرة. الجنين أحادي الفلقة به فلقة واحدة؛ الجنين ثنائي الفلقة به فلقتين.

countercurrent exchange The transfer of a substance or heat between two fluids flowing in opposite directions.

التبادل المعاكس تحول المواد أو الحرارة بين سائلين متدفقين في اتجاهين عكسيين.

covalent bond (ko-vā′-lent) A strong chemical bond in which two atoms share one or more pairs of outer-shell electrons.

الرابط التساهمي رابط كيميائي قوي تشترك فيه ذرتان مع زوج أو أكثر من الإلكترونات على القشرة الخارجية.

crista (kris′tuh) (plural, **cristae**) An infolding of the inner mitochondrial membrane.

العرف (الجمع أعراف) إطواء للغشاء المتقدري الداخلي.

crop A pouch-like organ in a digestive tract where food is softened and may be stored temporarily.

الحوصلة عضو يشبه الكيس في السبيل الهضمي حيث يتم فيه تليين وتخزين الطعام بصورة مؤقتة.

cross A mating of two sexually reproducing individuals; often used to describe a genetics experiment involving a controlled mating (a "genetic cross").

هجين تزاوج بين فردين متوالدين جنسيا؛ تستخدم غالبا لوصف التجارب الجينية التي تشتمل على تزاوج بشواهد (هجين جيني).

cross-fertilization The fusion of sperm and egg derived from two different individuals.

إخصاب متصالب اندماج حيوان منوي وبيضة منشق من فردين مختلفين.

cuticle (kyū′-tuh-kul) (1) In animals, a tough, nonliving outer layer of the skin. (2) In plants, a waxy coating on the surface of stems and leaves that helps retain water.

الجليدة (1) في الحيوانات، طبقة خارجية من الجلد قوية وغير حية. (2) في النباتات، غلاف شمعي على سطح السوق والأوراق والتي تمنع احتجاز الماء.

cytokinesis (sī′-tō-kuh-nē-sis) The division of the cytoplasm to form two separate daughter cells. Cytokinesis usually occurs in conjunction with telophase of mitosis. Mitosis and cytokinesis make up the mitotic (M) phase of the cell cycle.

الحرائك الخلوية انقسام الهيولي لتكوين الخلايا الوليدة. تحدث الحرائك الخلوية بالتزامن مع الطور الانتهائي للتفتل. التفتل والحرائك الخلوية تشكل الانقسام الفتيلي (M) لدورة الخلية.

cytokinin (sī′-tō-kī′-nin) One of a family of plant hormones that promotes cell division, retards aging in flowers and fruits, and may interact antagonistically with auxins in regulating plant growth and development.

سيتوكاينين واحد من عائلة هرمونات النباتات التي تساعد على انقسام الخلايا، والتي تأخر الشيخوخة في الأزهار والفواكه، وربما تتفاعل بصورة مضادة مع الأوكسينات في تنظيم نمو وتطور النبات.

cytoplasm(si′-tō-plaz′-um) The contents of a eukaryotic cell between the plasma membrane and the nucleus; consists of a semifluid medium and organelles; can also refer to the interior of a prokaryotic cell.

السيتوبلازم محتويات الخلية الحيوانية بين غشاء البلازما والنواة؛ تتكون من وسائط شبه سائلة وعضيات؛ يمكن أن تشير أيضا إلى داخل الخلية بدائية النواة.

cytosine (C) (sī′-tuh-sin) A single-ring nitrogenous base found in DNA and RNA.

سيتوزين (C) قاعدة نيتروجينية أحادية الحلقات موجودة في الدنا والرنا.

cytoskeleton A network of protein fibers in the cytoplasm of a eukaryotic cell; includes microfilaments, intermediate filaments, and microtubules.

هيكل الخلية شبكة من ألياف البروتينات في الستيوبلازم للخلية الحيوانية؛ يشتمل على خيوط دقيقة وخيوط متوسطة والأنيبيبات.

D

decomposer Prokaryotes and fungi that secrete enzymes that digest nutrients from organic material and convert them to inorganic forms.

محلل أحاديات النواة وفطريات تفرز إنزيمات تساعد على هضم المواد الغذائية من المواد العضوية وتحويلها إلى صورة غير عضوية.

decomposition The breakdown of organic materials into inorganic ones.

التحلل تكسر المواد العضوية إلى مواد غير عضوية.

deductive reasoning A type of logic in which specific results are predicted from a general premise.

المنطق الاستنباطي نوع من المنطق يتم فيه التنبؤ بنتائج معينة من مقدمات عامة.

dehydration reaction (dē-hī-drā′-shun) A chemical reaction in which two molecules become covalently bonded to each other with the removal of a water molecule.

تفاعلات التجافف تفاعل كيميائي يصبح فيه جزيئان مرتبطين ببعضهما بعضا مع إزالة جزء الماء.

denaturation (dē-nā′-chur-ā′-shun) A process in which a protein unravels, losing its specific structure and hence function; can be caused by changes in pH or salt

concentration or by high temperature; also refers to the separation of the two strands of the DNA double helix, caused by similar factors.

تمسخ عملية يظهر فيها البروتين، ويفقد بناؤه المحدد ومن ثم وظيفته؛ يمكن أن يحدث ذلك بسبب تغيرات في تركيز pH أو الملح أو بسبب زيادة درجة الحرارة؛ كما يشير أيضا إلى فصل طيقين من الحلز المزدوج للدنا، والذي يحدث بسبب عوامل مشابهة.

deoxyribonucleic acid (DNA) (dē-ok′-sē-rī′-bō-nū-klā′-ik) A double-stranded helical nucleic acid molecule consisting of nucleotide monomers with deoxyribose sugar and the nitrogenous bases adenine (A), cytosine (C), guanine (G), and thymine (T). Capable of replicating, DNA is an organism's genetic material. *See also* gene.

الحمض الريبي النووي المنزوع الأوكسجين (DNA) جزيء حمض نووي حلزوني مزدوج الطيقان يتألف من مونومر النوكليوتيد مع الريبوز منزوع الأوكسجين وأدينين القاعدة النيتروجينية (A) وسيتوزين (C) والغوانين (G) والثيمين (T). يستطيع التكرار، DNA عبارة عن مادة جينية للكائن الحي. انظر أيضا الجين.

dermal tissue system The outer protective covering of plants.

نظام النسيج الجلدي الغطاء الوقائي الخارجي للنباتات.

detritus (duh-trī′-tus) Dead organic matter.

حتات مادة عضوية ميتة.

diaphragm (dī′-uh-fram) The sheet of muscle separating the chest cavity from the abdominal cavity in mammals. Its contraction expands the chest cavity, and its relaxation reduces it.

الحجاب لوح من العضلات يفصل تجويف الصدر من تجويف البطن في الثدييات. انقباضها يوسع تجويف الصدر وانبساطها يضيق التجويف.

diastole (dȳ′-as′-to-lē) The stage of the heart cycle in which the heart muscle is relaxed, allowing the chambers to fill with blood. *See also* systole.

الانبساط مرحلة دورة القلب التي يحدث فيها انبساط لعضلات القلب، مما يسمح بملء الغرف بالدم. انظر أيضا الانقباض.

dicot (dī′-kot) A term traditionally used to refer to flowering plants that have two embryonic seed leaves, or cotyledons.

ثنائي الحبات مصطلح يستخدم بصورة تقليدية للإشارة إلى النباتات المزهرة التي تحتوي على أوراق زهرية جنينية أو طفلق.

diffusion The spontaneous movement of a substance down its concentration gradient from where it is more concentrated to where it is less concentrated.

الانتشار حركة تلقائية للمادة تحت مدروج التركيز الخاص بها من الأماكن التي تكون فيها أكثر تركيزا إلى الأماكن التي تكون فيها أقل تركيزا.

digestion The mechanical and chemical breakdown of food into molecules small enough for the body to absorb; the second stage of food processing in animals.

الهضم التكسر الميكانيكي والكيميائي للطعام إلى جزيئات صغيرة لدرجة يستطيع الجسم امتصاصها؛ المرحلة الثانية من التمثيل الغذائي في الحيوانات.

digestive system The organ system involved in ingestion and digestion of food, absorption of nutrients, and elimination of wastes.

الجهاز الهضمي النظام العضوي المسئول عن ابتلاع وهضم الطعام، وامتصاص المواد الغذائية والتخلص من الفضلات.

diploid In an organism that reproduces sexually, a cell containing two homologous sets of chromosomes, one set inherited from each parent; a $2n$ cell.

الصبيغات في الكائن الحي الذي يتوالد جنسيا، خلية تحتوي على مجموعتين متطابقتين من الكروموسومات، مجموعة موروثة من كل أب؛ خلية 2n.

disaccharide (dī-sak′-uh-rīd) A sugar molecule consisting of two monosaccharides linked by a dehydration reaction.

ثنائي السكاريد جزيء سكر يتكون من أحادي السكاريد مرتبط عن طريق تفاعلات الجفاف.

DNA *See* deoxyribonucleic acid (DNA).

DNA انظر الحمض الريبي النووي المنزوع الأوكسجين (DNA).

DNA ligase (lī′-gās) An enzyme, essential for DNA replication, that catalyzes the covalent bonding of adjacent DNA polynucleotide strands. DNA ligase is used in genetic engineering to paste a specific piece of DNA containing a gene of interest into a bacterial plasmid or other vector.

ليغاز الدنا أنزيم، ضروري لتنسخ الدنا والذي يحفز الرابط التساهمي مع طيقان عديد النوكليوتيد للدنا. يستخدم الليغاز في الهندسة الوراثية للصق نوع معين من الدنا يحتوي على جين مهتم بالبلازميدة البكتيرية أو غيرها من الناقلات.

DNA polymerase (puh-lim′-er-ās) A large molecular complex that assembles DNA nucleotides into polynucleotides using a preexisting strand of DNA as a template.

بوليميراز الدنا تركيبة جزيئية ضخمة تجمع نوكليوتيدات الدنا في عديد النوكليوتيد باستخدام طيقان موجودة مسبقا في الدنا كقوالب.

DNA profiling A procedure that analyzes DNA samples to determine if they came from the same individual.

تصوير الدنا إجراء يحلل عينات الدنا لتحديد ما إذا كانت من نفس الفرد.

domain A taxonomic category above the kingdom level. The three domains of life are Archaea, Bacteria, and Eukarya.

المجال فئة تصنيفية فوق مستوى المملكة. العوالم الثلاث للحياة هي البدائيات والبكتيريا وحقيقية النواة.

dominant allele The allele that determines the phenotype of a gene when the individual is heterozygous for that gene.

الأليل السائد الأليل الذي يحدد النمط الظاهري للجين عندما يكون الفرد متغاير الزيجوت لهذا الجين.

dorsal Pertaining to the back of a bilaterally symmetric animal.

ظهري متعلق بظهر الحيوان المتماثل ثنائيا.

double circulation A circulatory system with separate pulmonary and systemic circuits, in which blood passes through the heart after completing each circuit; ensures vigorous blood flow to all organs.

الدورة المزدوجة نظام دوري به دوائر رئوية ونظامية مستقلة، يمر خلالها الدم عبر القلب بعد استكمال كل دورة؛ والذي يضمن حدوث تدفق دم شديد لجميع الأعضاء.

double fertilization In flowering plants, the formation of both a zygote and a cell with a triploid nucleus, which develops into the endosperm.

التخصيب المزدوج في النباتات المزهرة، تكون اللاقحة والخلية مع نواة ثلاثية الصيغة الصبغية والتي تتطور في السويداء.

double helix The form of native DNA, referring to its two adjacent polynucleotide strands interwound into a spiral shape.

الحلز المزدوج شكل الدنا الأصلي الذي يشير إلى طيقان عديدة النوكليوتيد المجاورة والتي تتكون في شكل حلزوني.

E

ectoderm (ek′-tō-derm) The outer layer of three embryonic cell layers in a gastrula. The ectoderm forms the skin of the gastrula and gives rise to the epidermis and nervous system in the adult.

الأديم الظاهر الطبقة الخارجية من ثلاث طبقات من الخلايا الجنينية في المعيدة. الأديم الظاهر يشكل جلد المعيدة ويؤدي إلى نمو البشرة والجهاز العصبي لدى البالغين.

ectopic pregnancy (ek-top′-ik) The implantation and development of an embryo outside the uterus.

حمل منتبذ انغراس ونمو للجنين خارج الرحم.

ectotherm (ek′-to-therm) An animal that warms itself mainly by absorbing heat from its surroundings. Examples include most amphibians, lizards, and invertebrates.

متغير الحرارة الحيوان الذي يدفئ نفسه بصورة رئيسية عن طريق امتصاص الحرارة من الغلاف المحيط. تشتمل الأمثلة على معظم البرمائيات والزواحف واللافقاريات.

ectothermic Referring to organisms that do not produce enough metabolic heat to have much effect on body temperature. *See also* ectotherm.

خارجية الحرارة تشير إلى الكائنات التي لا تنتج حرارة أيضية كافية يكون لها التأثير على درجة حرارة الجسم. انظر أيضا خارجي التنظيم الحراري.

effector cell (1) A muscle cell or gland cell that performs the body's response to stimuli, responding to signals from the brain or other processing center of the nervous system. (2) A lymphocyte that has undergone clonal selection and is capable of mediating an acquired immune response.

خلية مستفعلة (1) خلية عضلية أو خلية غدية تقوم بإجراء استجابة الجسم إلى المنبهات، للاستجابة إلى الإشارات من المخ أو غيرها من المراكز في الجهاز العصبي. (2) لمفاوية تقوم بإجراء انتقاء نسيلي وتستطيع التخلل في استجابة المناعة المكتسبة.

egg A female gamete.

البيضة العرس الأنثوي.

ejaculation (ih-jak′-yū-lā′-shun) Expulsion of semen from the penis.

القذف انقذاف المني من العضو الذكري.

ejaculatory duct The short section of the ejaculatory route in mammals formed by the convergence of the vas deferens and a duct from the seminal vesicle. The ejaculatory duct transports sperm from the vas deferens to the urethra.

القناة الدافقة الجزء القصير في الممر الدافقي في الثدييات يتشكل عن طريق تقارب القناة الناقلة للمني والقناة من الحويصلة المنوية. تقوم القناة الدافقة بنقل الحيوان المنوي من القناة الناقلة للمني إلى الإحليل.

electromagnetic spectrum The entire spectrum of radiation ranging in wavelength from less than a nanometer to more than a kilometer.

الطيف الكهرومغناطيسي الطيف الكامل من الإشعاع الذي يتروح في طول الموجة من أقل من نانومتر إلى أكثر من كيلومتر.

electron A subatomic particle with a single negative electrical charge. One or more electrons move around the nucleus of an atom.

الإلكترون جسيم دوين الذرة به شحنة كهربائية سالبة واحدة. يتحرك إلكترون أو أكثر حول نواة الذرة.

electron microscope (EM) A microscope that uses magnets to focus an electron beam through, or onto the surface of, a specimen. An electron microscope achieves a hundredfold greater resolution than a light microscope.

المجهر الإلكتروني (EM) مجهر يستخدم المغناطيس لتركيز شعاع الإلكترون من خلال سطح العينة أو عليها. يحقق المجهر الإلكتروني نتائج أعلى بكثير من المجهر الضوئي.

electron shell An energy level representing the distance of an electron from the nucleus of an atom.

محار إلكتروني مستوى الطاقة الذي يمثل المسافة بين إلكترون من النواة إلى الذرة.

electron transport chain A series of electron carrier molecules that shuttle electrons during the redox reactions that release energy used to make ATP; located in the inner membrane of mitochondria, the thylakoid membranes of chloroplasts, and the plasma membranes of prokaryotes.

سلسلة ناقل الإلكترون سلسلة من الجزيئات الحاملة للإلكترونات تنقل الإلكترونات أثناء تفاعلات الأكسدة والاختزال التي تبعث الطاقة المستخدمة لعمل ATP؛ التي تقع في الغشاء الداخلي للمتقدرات، غشاء التيلاكويدات لصانعات الكلوروفيل وأغشية البلازما لبدائيات النواة.

electronegativity The attraction of a given atom for the electrons of a covalent bond.

كهربية سلبية انجذاب ذرة معينة للإلكترونات للرابط التساهمي.

element A substance that cannot be broken down to other substances by chemical means.

العنصر مادة لا يمكن تكسيرها إلى مواد أخرى عن طريق الوسائل الكيميائية.

elimination The passing of undigested material out of the digestive compartment; the fourth and final stage of food processing in animals.

الإطراح خروج المواد غير المهضومة خارج الحيز الهضمي؛ المرحلة الرابعة والأخيرة من التمثيل الغذائي في الحيوانات.

embryo (em′-brē-ō) A developing stage of a multicellular organism. In humans, the stage in the development of offspring from the first division of the zygote until body structures begin to appear, about the 9th week of gestation.

الجنين مرحلة متطورة في الكائنات الحية متعددة الخلايا. في الإنسان، مرحلة في تطور السلالة من الانقسام الأول للزيجوت حتى يبدأ بناء الجسم في الظهور، حوالي الأسبوع التاسع من الحمل.

embryo sac The female gametophyte contained in the ovule of a flowering plant.

كيس الجنين النابتة العرسية الأنثوية الموجودة في بيضة النبات المزهر.

emergent properties New properties that arise with each step upward in the hierarchy of life, owing to the arrangement and interactions of parts as complexity increases.

الخصائص الظاهرة الخصائص الجديدة التي تظهر مع كل مرحلة في تسلسل الحياة، بسبب ترتيبات وتفاعلات الأجزاء كلما زاد التعقد.

endocrine gland (en′-dō-krin) A ductless gland that synthesizes hormone molecules and secretes them directly into the bloodstream.

الغدة الصماء غدة صماء تخلق جزيئات الهرمون وتفرزها بصورة مباشرة في مجرى الدم.

endocrine system (en′-dō-krin) The organ system consisting of ductless glands that secrete hormones and the molecular receptors on or in target cells that respond to the hormones. The endocrine system cooperates with the nervous system in regulating body functions and maintaining homeostasis.

الجهاز الصماوي الجهاز العضوي الذي يتكون من غدد صماء تفرز هرمونات ومستقبلات جزيئية أو في الخلايا المستهدفة التي تستجيب للهرمونات. يتعاون الجهاز الصماوي مع الجهاز العصبي في تنظيم وظائف الجسم والحفاظ على الاستتباب.

endocytosis (en′-dō-sī-tō′-sis) Cellular uptake of molecules or particles via formation of new vesicles from the plasma membrane.

الالتقام انطلاق خلوي للجزيئات أو الجسيمات من خلال تكوين جسيمات جديدة من غشاء البلازما.

endoderm (en′-dō-derm) The innermost of three embryonic cell layers in a gastrula; forms the archenteron in the gastrula and gives rise to the innermost linings of the digestive tract and other hollow organs in the adult.

الأديم الباطن الطبقة الداخلية من ثلاث طبقات من الخلايا الجنينية في المعيدة. يشكل جلد المعي البدائي في المعيدة ويؤدي إلى نمو البطانة الداخلية للسبيل الهضمي والأعضاء المجوفة الأخرى.

endodermis The innermost layer (a one-cell-thick cylinder) of the cortex of a plant root; forms a selective barrier determining which substances pass from the cortex into the vascular tissue.

البشرة الداخلية الطبقة الداخلية (أسطوانة في سمك الخلية الواحدة) من قشرة جذر النبات؛ تشكل حاجز انتقائي والذي يحدد المواد التي تمر من القشرة إلى النسيج الوعائي.

endomembrane system A network of membranes inside and around a eukaryotic cell, related either through direct physical contact or by the transfer of membranous vesicles.

جهاز الغشاء الداخلي شبكة من الأغشية داخل وحول الخلية الحيوانية، مرتبطة إما من خلال اتصال فيزيائي مباشر أو نقل الجسيمات الغشائية.

endometrium (en′-dō-mē′-trē-um) The inner lining of the uterus in mammals, richly supplied with blood vessels that provide the maternal part of the placenta and nourish the developing embryo.

بطانة الرحم البطانة الداخلية من الرحم في الثدييات، الغنية بالأوعية الدموية التي توفر الجزء الأمومي من المشيمة ويغذي الجنين.

GLOSSARY

endoplasmic reticulum (ER) An extensive membranous network in a eukaryotic cell, continuous with the outer nuclear membrane and composed of ribosome-studded (rough) and ribosome-free (smooth) regions. *See also* rough ER; smooth ER.

الشبكة الهيولية الباطنة (ER) شبكة غشائية مركزة في الخلية الحيوانية، متصلة مع الغشاء النووي الخارجي ومؤلفة من مناطق غنية بالريبوسوم (قوية) ومناطق خالية من الريبوسوم (لينة). انظر أيضا ER القوية و ER اللينة.

endosperm In flowering plants, a nutrient-rich mass formed by the union of a sperm cell with two polar nuclei during double fertilization; provides nourishment to the developing embryo in the seed.

السويداء في النباتات الزهرية، كتلة غنية بالمواد الغذائية تتشكل عن طريق اتحاد خلية الحيوان المنوي مع نوي قطبي أثناء الإخصاب المزدوج؛ مما يوفر التغذية للجنين الذي ينمو في البذرة.

endotherm An animal that derives most of its body heat from its own metabolism. Examples include most mammals and birds.

داخلي الاستحرار حيوان يشتق معظم حرارته من الأيض الخاص به. تشتمل الأمثلة على معظم الثدييات والطيور.

endothermic Referring to animals that use heat generated by metabolism to maintain a warm, steady body temperature. *See also* endotherm.

ثابت الحرارة تشير إلى الحيوانات التي تستخدم الحرارة المولدة عن طريق الأيض للحفاظ على التدفئة وثبات درجة الحرارة. انظر أيضا داخلي الاستحرار.

energy The capacity to cause change, especially to perform work.

الطاقة القدرة على إحداث التغيير، خاصة لإجراء الأعمال.

entropy (en′-truh-pē) A measure of disorder. One form of disorder is heat, which is random molecular motion.

اعتلاج قياس للخلل أحد أشكال الخلل في الحرارة، عبارة عن حركة جزيئية عشوائية.

enzyme (en′-zīm) A macromolecule, usually a protein, that serves as a biological catalyst, changing the rate of a chemical reaction without being consumed by the reaction.

الإنزيم جزيء دقيق، يكون عادة بروتين يعمل كعامل حفاز حيوي، يؤدي إلى تغيير معدل التفاعلات الكيميائية دون استهلاكها عن طريق التفاعل.

epidermis (ep′-uh-der′-mis) (1) In animals, one or more living layers of cells forming the protective covering, or outer skin. (2) In plants, the tissue system forming the protective outer covering of leaves, young stems, and young roots.

البشرة(1) في الحيوانات، طبقة واحدة أو أكثر من طبقات الخلايا التي تشكل الغطاء الوقائي للجلد الخارجي. (2) في النباتات، نظام الأنسجة الذي يشكل الغطاء الوقائي الخارجي للأوراق والسوق والجذور الصغيرة.

epididymis (ep′-uh-did′-uh-mus) A long coiled tube into which sperm pass from the testis and are stored until mature and ejaculated.

البربخ أنبوب طويل ملفوف تمر خلاله الحيوانات المنوية من الخصية ويتم تخزينها حتى تنضج ويتم قذفها.

epithelial tissue (ep′-uh-thē′-lē-ul) A sheet of tightly packed cells lining organs, body cavities, and external surfaces; also called epithelium.

النسيج الظهاري لوح من أعضاء مبطنة بالخلايا، تجويفات في الجسم وأسطح خارجية تسمى أيضا ظهارة.

esophagus (eh-sof′-uh-gus) A muscular tube that conducts food by peristalsis, usually from the pharynx to the stomach.

المريء أنبوب عضلي يقوم بتمثيل الغذاء عن طريق التمعج، عادة من البلعوم إلى المعدة.

essential amino acid An amino acid that an animal cannot synthesize itself and must obtain from food. Eight amino acids are essential for the human adult.

حمض أميني ضروري حمض أميني لا يستطيع الحيوان تخليقه بنفسه ويحصل عليه من الطعام. ثمان أحماض أمينية ضرورية للإنسان البالغ.

essential element In plants, a chemical element required for the plant to complete its life cycle (to grow from a seed and produce another generation of seeds).

العنصر الضروري في النباتات، عنصر كيميائي مطلوب للنبات لإكمال دورة حياته (للنمو من البذرة وإنتاج جيل جديد من البذور).

essential fatty acid An unsaturated fatty acid that an animal needs but cannot make.

الحمض الدهني الضروري حمض دهني غير مشبع يحتاجه الحيوان ولكنه لا يستطيع تكوينه.

essential nutrient A substance that an organism must absorb in preassembled form because it cannot synthesize it from any other material. In humans, there are essential vitamins, minerals, amino acids, and fatty acids.

المواد الغذائية الضرورية مادة يجب أن يمتصها الكائن الحي في صورة مجمعة لأنه لا يستطيع تخليقها من أي مادة أخرى. في الإنسان، عبارة عن فيتامينات ومعادن وأحماض أمينية ومعادن وأحماض دهنية ضرورية.

estrogen (es′-trō-jen) One of several chemically similar steroid hormones secreted by the gonads; maintains the female reproductive system and promotes the development of female body features.

إستروجين أحد الهرمونات الستيرويدية المتشابهة كيميائيا التي تفرزها الغدة التناسلية؛ تحافظ على الجهاز الإنجابي وتساعد على نمو معالم الجسم الأنثوي.

ethylene A gas that functions as a hormone in plants, triggering aging responses such as fruit ripening and leaf drop.

الإيثيلين غاز يعمل كهرمون في النباتات، يحدد بدء استجابات الشيخوخة مثل نضج الفاكهة وتساقط الأوراق.

eudicot (yū-dē-kot) Member of a group that consists of the vast majority of flowering plants that have two embryonic seed leaves, or cotyledons.

متعدد البذور عضو في مجموعة تتألف من الغالبية العظمى من النباتات المزهرة التي تحتوي على أوراق زهرية جنينية أو طفلق.

Eukarya (yū-kar′-ē-uh) Domain of life that includes all eukaryotes.

حقيقية النواة مملكة من ممالك الحياة التي تحتوي على جميع حقيقي النواة.

eukaryotic cell (yū-kar-ē-ot′-ik) A type of cell that has a membrane-enclosed nucleus and other membrane-enclosed organelles. All organisms except bacteria and archaea are composed of eukaryotic cells.

الخلية الحيوانية نوع من الخلايا به نواة مغلفة بالغشاء وعضيات مغلفة بالغشاء. جميع الكائنات ماعدا البكتيريا والبدائيات تتكون من خلايا حيوانية.

evaporative cooling The process in which the surface of an object becomes cooler during evaporation.

التبريد التبخيري عملية يصبح خلالها سطح الشيء أبرد أثناء التبخير.

excretion (ek-skrē′-shun) The disposal of nitrogen-containing metabolic wastes.

الإخراج التخلص من الفضلات الأيضية التي تحتوي على النيتروجين.

exocytosis (ek′-sō-sī-tō′-sis) The movement of materials out of the cytoplasm of a cell by the fusion of vesicles with the plasma membrane.

إيماس حركة المواد خارج هيولي الخلية عن طريق اندماج الجسيمات مع غشاء البلازما.

external fertilization The fusion of gametes that parents have discharged into the environment.

التخصيب الخارجي اندماج الأعراس التي تتخلص منها الآباء في البيئة.

F

F_1 generation The offspring of two parental (P generation) individuals; F_1 stands for first filial.

جيل F_1 نسل فردين أبوين (جيل P)؛ F_1 تعني البنوي الأول.

F_2 generation The offspring of the F_1 generation; F_2 stands for second filial.

جيل F_2 نسل جيل F_1؛ F_2 تعني البنوي الثاني.

facilitated diffusion The passage of a substance through a specific transport protein across a biological membrane down its concentration gradient.

انتشار ميسر مرور المادة خلال بروتين نقال محدد عبر الغشاء الحيوي تحت مدروج التركيز.

family In Linnaean classification, the taxonomic category above genus.

الأسرة في التصنيف الحيوي، الفئة التصنيفية فوق الجنس.

fat A lipid composed of three fatty acids linked to one glycerol molecule; a triglyceride. Most fats function as energy-storage molecules.

الدهون شحم مؤلف من ثلاث أحماض دهنية مرتبطة بجزيء الغليسيرول؛ ثلاثي الغليسريد. تعمل معظم الدهون كجزيئات لتخزين الطاقة.

feces The wastes of the digestive tract.

الغائط فضلات السبيل الهضمي.

fertilization The union of the nucleus of a sperm cell with the nucleus of an egg cell, producing a zygote.

التخصيب اتحاد نواة خلية الحيوان المنوي مع نواة خلية البويضة، لإنتاج الزيجوت.

fertilizer A compound given to plants to promote their growth.

المخصب مركب يتم تقديمه للنباتات للمساعدة على النمو.

fiber (1) In animals, an elongate, supportive thread in the matrix of connective tissue; an extension of a neuron; a muscle cell. (2) In plants, a long, slender sclerenchyma cell that usually occurs in a bundle.

الألياف (1) في الحيوانات، خيط طويل دعامي في مصفوفة الأنسجة الضامة؛ تمديد العصبون؛ خلية عضلية. (2) في النباتات، خلايا النسيج الداعم التي تتكون عادة في مجموعات.

fibrin (fȳ′-brin) The activated form of the blood-clotting protein fibrinogen, which aggregates into threads that form the fabric of a blood clot.

الفبرين الصور الفعالة لفبرينوجين بروتين تخثر الدم، والذي يتجمع في خيوط تشكل تخثر الدم.

fibrinogen (fȳ′-brin′-uh-jen) The plasma protein that is activated to form a clot when a blood vessel is injured.

الفبرينوجين بروتين البلازما الذي ينشط لتكوين الجلطة عند إصابة الأوعية الدموية.

fibrous connective tissue A dense tissue with large numbers of collagenous fibers organized into parallel bundles. This is the dominant tissue in tendons and ligaments.

النسيج الضام الليفي نسيج كثيف يحتوى على اعداد كبيرة من الألياف الكولاجينيه المرتبة في حزم متوازية. و هذا هو النسيج المهيمن في الأربطة و الأوتار.

filtrate Fluid extracted by the excretory system from the blood or body cavity. The excretory system produces urine from the filtrate after removing valuable solutes from it and concentrating it.

رشاحة سائل يستخرج بواسطة النظام المطرح من الدم أو تجويف الجسم. النظام المطرح ينتج البول من الرشاحة بعد إزاله المواد الذائبة المهمة و تركيزها.

first law of thermodynamics The principle of conservation of energy. Energy can be transferred and transformed, but it cannot be created or destroyed.

القانون الأول للديناميكية الحرارية مبدأ حفظ الطاقة. الطاقة يمكن أن تنتقل أو تتحول، لكن لا يمكن خلقها أو تدميرها.

fission A means of asexual reproduction whereby a parent separates into two or more genetically identical individuals of about equal size.

الانشطار طريقه للتكاثر اللاجنسي عندما ينفصل الأصل إلى اثنين أو أكثر من الأفراد المتطابقة جينيا وتقريبًا في نفس الحجم.

flagellum (fluh-jel′-um) (plural, **flagella**) A long cellular appendage specialized for locomotion. The flagella of prokaryotes and eukaryotes differ in both structure and function. Like cilia, eukaryotic flagella have a 9 + 2 arrangement of microtubules covered by the cell's plasma membrane.

سوط (الجمع سياط) زائدة خلوية طويلة مخصصة للحركة. سياط بدائيات النواة وحقيقية النواة تختلف في التركيب والوظيفة. مثل الأهداب، سياط حقيقي النواة بها أنيبيبات مرتبة في وضع 9 + 2 مغطاه بغشاء البلازما الخاص بالخلية.

fluid feeder An animal that lives by sucking nutrient-rich fluids from another living organism.

المتغذي على السوائل حيوان يعيش عن طريق مص المواد الغذائية الغنية بالسوائل من الكائنات الحية الأخرى.

fluid mosaic A description of membrane structure, depicting a cellular membrane as a mosaic of diverse protein molecules embedded in a fluid bilayer of phospholipid molecules

مزيق السوائل وصف لبناء الغشاء، والذي يصف غشاء الخلية كمزيق لجزيئات البروتين المتنوعة الموجودة في طبقات سوائل ثنائية من الجزيئات الشحمية الفسفورية.

follicle (fol′-uh-kul) A cluster of cells that surround, protect, and nourish a developing egg cell in the ovary. Follicles secrete the hormone estrogen.

الجريب عنقود من الخلايا التي تحيط بخلية البويضة النامية في المبيض وتحميها وتغذيها. يفرز الجريب هرمون الإستروجين.

food chain A sequence of food transfers from producers through one to four levels of consumers in an ecosystem.

سلسلة الطعام تسلسل من تنقلات الطعام من منتجي الطعام خلال مرحلة من أربع مراحل للمستهلكين في الوحدة الأيكولوجية الأساسية.

forensics The scientific analysis of evidence for crime scene and other legal proceedings. Also referred to as forensic science.

الطب الشرعي التحليل العلمي لأدلة مشهد الجريمة وغيرها من الإجراءات القانونية. المشار إليها باسم العلم الشرعي.

fossil A preserved remnant or impression of an organism that lived in the past.

الأحفورة بقاوة أو طابع محفوظ لكائن حي عاش في الماضي.

founder effect Genetic drift that occurs when a few individuals become isolated from a larger population and form a new population whose gene pool is not reflective of that of the original population.

تأثير المنشيء انزياح جيني يحدث عندما تصبح مجموعة قليلة من الأفراد معزولة عن عينة كبيرة وتشكل عينة جديدة لا تعكس فيها تجميعة الجينات العينة الأصلية.

fragmentation A means of asexual reproduction whereby a single parent breaks into parts that regenerate into whole new individuals.

التعدد وسيلة للتوالد اللاجنسي حيث يتكسر أب مفرد إلي أجزاء تتوالد لتصبح أفرادًا جدد مكتملين.

fruit A ripened, thickened ovary of a flower, which protects developing seeds and aids in their dispersal.

الفاكهة المبيض الناضج من الزهرة، والذي يحمي البذور النامية ويساعد على تبعثرها.

functional group A specific configuration of atoms commonly attached to the carbon skeletons of organic molecules and involved in chemical reactions.

المجموعة الوظيفية تهيئة محددة للذرات ترتبط بصورة شائعة بالهيكل الكربوني للجزيئات العضوية وتشترك في التفاعلات الكيميائية.

Fungi (fun′-ji) The kingdom that contains the fungi.

الفطر مملكة تحتوي على الفطريات.

G

gamete (gam′-ēt) A sex cell; a haploid egg or sperm. The union of two gametes of opposite sex (fertilization) produces a zygote.

العرس خلية جنسية؛ بويضة أو حيوان منوي فرداني. اتحاد عرسين من جنسين مختلفين (إخصاب) يؤدي إلى توليد الزيجوت.

GLOSSARY

gametogenesis The creation of gametes within the gonads.

تكون الأعراس خلق الأعراس في الغدد التناسلية.

gametophyte (guh-mē′-tō-fīt) The multicellular haploid form in the life cycle of organisms undergoing alternation of generations; mitotically produces haploid gametes that unite and grow into the sporophyte generation.

النابتة العرسية الشكل الفرداني متعدد الخلايا في دورة حياة الكائن الحي والتي تؤدي إلى تبديل الأجيال؛ والتي تنتج أعراسًا فردانية تتجمع وتنمو في جيل النابت البوغي.

gas exchange The exchange of O_2 and CO_2 between an organism and its environment.

تبادل الغازات تبادل الأوكجسين وثاني أكسيد الكربون بين الكائنات والبيئة من حولها.

gastrula (gas′-trū-luh) The embryonic stage resulting from gastrulation in animal development. Most animals have a gastrula made up of three layers of cells: ectoderm, endoderm, and mesoderm.

المعيدة المرحلة الجنينية التي تنتج من تكون المعيدة في نمو الحيوانات. معظم الحيوانات بها معيدة مؤلفة من ثلاث طبقات من الخلايا؛ الأديم الظاهر والأديم الباطن والأديم المتوسط.

gastrulation (gas′-trū-lā′-shun) The second major phase of embryonic development, which transforms the blastula into a gastrula. Gastrulation adds more cells to the embryo and sorts the cells into distinct cell layers.

تكون المعيدة المرحلة الرئيسية الثانية من تطور الجنين، والتي تقوم بتحويل الأريمة إلى المعيدة. تكون المعيدة يضيف مزيدًا من الخلايا إلى الجنين ويصنف الخلايا إلى طبقات خلايا قائمة بذاتها.

gene A discrete unit of hereditary information consisting of a specific nucleotide sequence in DNA (or RNA, in some viruses). Most of the genes of a eukaryote are located in its chromosomal DNA; a few are carried by the DNA of mitochondria and chloroplasts.

الجين وحدة منعزلة من المعلومات الوراثية التي تتألف من تسلسل نوكليوتيد محدد في الدنا (أو الرنا في بعض الفيروسات). جميع الجينات في حقيقي النواة تقع في الدنا الكروموسومي؛ يتم نقل القليل منها عن طريق المتقدرات والبلاستيدات الخضراء.

genetic engineering The direct manipulation of genes for practical purposes.

الهندسة الوراثية التداول المباشر للجينات لأهداف عملية.

genetics The scientific study of heredity. Modern genetics began with the work of Gregor Mendel in the 19th century.

علم الوراثة الدراسة العلمية للوراثة. بدأ علم الوراثة الحديث بأعمال جريجور مندل في القرن التاسع عشر.

genomics The study of whole sets of genes and their interactions.

الجنوميات دراسة المجموعات الكاملة للجينات وتفاعلاتها.

genotype (jē′-nō-tīp) The genetic makeup of an organism.

النمط الجيني الترتيب الوراثي للكائن الحي.

genus (jē′-nus) (plural, **genera**) In classification, the taxonomic category above species; the first part of a species' binomial; for example, *Homo*.

الجنس (الجمع **أجناس**) في التصنيف، الفئة التصنيفية فوق النوع؛ الجزء الأول من ثنائي الحدود للنوع؛ على سبيل المثال الإنسان.

germinate To start developing or growing.

إنبات بداية التطور والنمو.

gizzard A pouch-like organ in a digestive tract where food is mechanically ground.

حوصلة عضو يشبه الكيس في السبيل الهضمي حيث يتم فيه طحن الطعام ميكانيكيا.

glans The rounded, highly sensitive head of the clitoris in females and penis in males.

الحشفة الرأس المستديرة شديدة الحساسية في البظر لدى الإناث والعضو الذكري لدى الذكور.

glia A network of supporting cells that is essential for the structural integrity and normal functioning of the nervous system.

الدبق العصبي شبكة من الخلايا المساعدة الضرورية للتكامل الهيكلي والتوظيف الطبيعي للجهاز العصبي.

global climate change Increase in temperature and change in weather patterns all around the planet, due mostly to increasing atmospheric CO_2 levels from the burning of fossil fuels. The increase in temperature, called global warming, is a major aspect of global climate change.

التغير المناخي العالمي زيادة في درجة الحرارة وتغير في الطقس في جميع أنحاء الكوكب، بسبب زيادة مستويات ثاني أكسيد الكربون الغلافي من احتراق وقود الحفريات. زيادة درجة الحرارة والتي تسمى التدفئة العالمية، تعتبر مظهر رئيسي في التغير المناخي العالمي.

glucagon (glū′-kuh-gon) A peptide hormone, secreted by the islets of Langerhaus in the pancreas, that raises the level of glucose in the blood. It is antagonistic with insulin.

الغلوكاغون هرمون ببتيد، يفرز عن طريق جزر لانغرهانس في البنكرياس، والتي ترفع مستويات الجلوكوز في الدم. مضادة للأنسولين.

glycogen (glī′-kō-jen) An extensively branched glucose storage polysaccharide found in liver and muscle cells; the animal equivalent of starch.

غليكوجين سكاريد متعددة لتخزين الجلوكوز بكميات كبيرة موجود في الكبد والخلايا العضلية؛ المكافئ الحيواني للنشا.

glycolysis (glī-kol′-uh-sis) The multistep chemical breakdown of a molecule of glucose into two molecules of pyruvate; the first stage of cellular respiration in all organisms; occurs in the cytoplasmic fluid.

تحلل السكر التكسر الكيميائي متعدد المراحل لجزيء الجلوكوز إلى جزيئين من البيروفات؛ المرحلة الأولى من التنفس الخلوي للكائنات؛ يحدث ذلك عادة في السائل الهيولي.

glycoprotein (glī′-kō-prō′-tēn) A protein with one of more short chains of sugars attached to it.

البروتين السكري بروتين به واحد من العديد من سلاسل السكر المتصلة به.

Golgi apparatus (gol′-jē) An organelle in eukaryotic cells consisting of stacks of membranous sacs that modify, store, and ship products of the endoplasmic reticulum.

جهاز غولجي عضيات في الخلايا الحيوانية تتكون من مكدسات من الأكياس الغشائية التي تقوم بتعديل وتخزين وشحن منتجات الشبكة الهيولية الباطنة.

gonad A sex organ in an animal; an ovary or testis.

الغدة التناسلية عضو جنسي في الحيوانات، المبيض أو الخصية.

granum (gran′-um) (plural, **grana**) A stack of membrane-bounded thylakoids in a chloroplast. Grana are the sites where light energy is trapped by chlorophyll and converted to chemical energy during the light reactions of photosynthesis.

قمحة (الجمع **قمحات**) مدس من التيلاكويدات المغلفة بالأغشية في البلاستيدات الخضراء. القمحات هي الأماكن التي يتم فيها تجميع الطاقة الضوئية عن طريق الكلوروفيل وتحويلها إلى طاقة كيميائية أثناء التفاعلات الضوئية للتخليق الضوئي.

ground tissue system A tissue of mostly parenchyma cells that makes up the bulk of a young plant and is continuous throughout its body. The ground tissue system fills the space between the epidermis and the vascular tissue system.

النظام النسيجي الأساسي نسيج من خلايا المتن التي تشكل مجموعة من النباتات الصغيرة وتستمر في جسمها. يقوم النظام النسيجي الأساسي بملء الفراغات بين الظهارة والنظام النسجي الوعائي.

growth factor A protein secreted by certain body cells that stimulates other cells to divide.

عنصر النمو بروتين يتم إفرازه عن طريق خلايا جسدية محددة تحفز خلايا أخرى على الانقسام.

guanine (G) (gwa′-nēn) A double-ring nitrogenous base found in DNA and RNA.

الغوانين قاعدة نيتروجينية مزدوجة الحلقات موجودة في الدنا والرنا.

guard cell A specialized epidermal cell in plants that regulates the size of a stoma, allowing gas exchange between the surrounding air and the photosynthetic cells in the leaf.

الخلية الحارسة خلية أديمية متخصصة في النباتات تعمل على تنظيم حجم الفغرة، مما يسمح بتبادل الغازات بين الهواء المحيط وخلايا الجرثوم ضوئي التخليق في الأوراق.

H

habitat A place where an organism lives; the environment in which an organism lives.

الموئل مكان يعيش فيه الكائن الحي؛ بيئة يعيش فيها الكائن الحي.

haploid In the life cycle of an organism that reproduces sexually, a cell containing a single set of chromosomes; an *n* cell.

فرداني في دورة حياة الكائن الحي الذي يقوم بالتوالد جنسيا، خلية تحتوي على مجموعة مفردة من الكروموسومات، خلية n.

heart A muscular pump that propels a circulatory fluid (blood) through vessels to the body.

القلب مضخة عضلية تدفع السوائل الدورانية (الدم) من خلال الأوعية إلى الجسم.

heart murmur A hissing sound that most often results from blood squirting backward through a leaky valve in the heart.

النفخة القلبية صوت تنفس هسيسي ينتج من ضخ الدم للخلف خلال صمام راشح في القلب.

heart rate The frequency of heart contraction, usually expressed in number of beats per minute.

سرعة القلب تكرار انقباض القلب، يتم الإشارة إليه عادة عن طريق عدد دقات القلب في الدقيقة.

heat Thermal energy; the amount of energy associated with the movement of the atoms and molecules in a body of matter. Heat is energy in its most random form.

الحرارة الطاقة الحرارية؛ كمية الطاقة المرتبطة بحركة الذرات والجزيئات في الجسم. الحرارة هي الطاقة في معظم صورها العشوائية.

hemoglobin (hē′-mō-glō-bin) An iron-containing protein in red blood cells that reversibly binds O_2.

الهيموجلوبين بروتين يحتوي على حديد في خلايا الدم الحمراء التي تربط الماء بصورة عكسية.

herbivore An animal that mainly eats plants or algae. *See also* carnivore; omnivore.

العاشب حيوان يعيش بصورة رئيسية على النباتات أو الطحالب. انظر أيضا اللاحم؛ القارت.

heredity The transmission of traits (inherited features) from one generation to the next.

الوراثة نقل الخصائص (الصفات الموروثة) من جيل إلى آخر.

hermaphroditism (her-maf′-rō-dī-tizm) A condition in which an individual has both female and male gonads and functions as both a male and female in sexual reproduction by producing both sperm and eggs.

الخنوثة حالة يكون فيها الفرد لديه غدد تناسلية أنثوية وذكورية ويعمل كذكر وأنثى في التوالد الجنسي عن طريق إنتاج حيوانات منوية وبويضات.

heterotroph (het′-er-ō-trōf) An organism that cannot make its own organic food molecules and must obtain them by consuming other organisms or their organic products; a consumer or a decomposer in a food chain.

غيري التغذي كائن حي لا يستطيع عمل جزيئات الأطعمة العضوية الخاصة به ويجب أن يحصل عليها عن طريق استهلاك كائنات حية أخرى أو منتجاتها العضوية؛ مستهلك أو محلل في السلسلة الغذائية.

heterozygous (het′-er-ō-zī′-gus) Having two different alleles for a given gene.

متخالف به أليلان مختلفان لجين واحد.

hippocampus (hip′-uh-kam′-pus) An integrative center of the cerebrum; functionally, the part of the limbic system that plays a central role in the formation of memories and their recall.

الحصين مركز تكاملي للدماغ؛ من حيث الوظيفة هو الجزء من الجهاز الحوفي الذي يلعب دورا مركزيا في تكون الذكريات واستدعائها.

homeobox (hō′-mē-ō-boks′) A 180-nucleotide sequence within a homeotic gene and some other developmental genes.

جينات الصندوق المثلي تسلسل يتألف من 180 نيوكليوتيد في جين مثلي والبعض من الجينات النامية.

homeostasis (hō′-mē-ō-stā′-sis) The steady state of body functioning; a state of equilibrium characterized by a dynamic interplay between outside forces that tend to change an organism's internal environment and the internal control mechanisms that oppose such changes.

الاستتباب الحالة الثابتة لوظائف الجسم؛ حالة من التوازن تتسم بالتفاعل الديناميكي بين القوى الخارجية التي تميل إلى تغيير البيئة الداخلية للكائن الحي وآليات التحكم الداخلية التي تتعارض مع ذلك التغيير.

homologous chromosomes (hō-mol′-uh-gus) The two chromosomes that make up a matched pair in a diploid cell. Homologous chromosomes are of the same length, centromere position, and staining pattern and possess genes for the same characteristics at corresponding loci. One homologous chromosome is inherited from the organism's father, the other from the mother.

صبغيان متماثلان الصبغيان اللذان يشكلان زوج متشابه في خلية ضعفانية. يكون الصبغيان متماثلان في نفس الطول ووضع سنترومير ونموذج محدد ويحتويان على جينات بنفس الصفات في مواضع متصلة. يأتي أحد الصبغين المتماثلين من أب الكائن الحي؛ والآخر من الأم.

homologous structures Structures in different species that are similar because of common ancestry.

الهياكل المتماثلة هياكل بأنواع مختلفة متشابهة بسبب أصول متشابهة.

homozygous (hō′-mō-zī′-gus) Having two identical alleles for a given gene.

الزيجوت المتماثلة الألائل بها أليلان متماثلان لجين واحد.

hormone (1) In animals, a regulatory chemical that travels in the blood from its production site, usually an endocrine gland, to other sites, where target cells respond to the regulatory signal. (2) In plants, a chemical that is produced in one part of the plant and travels to another part, where it acts on target cells to change their functioning.

الهرمون (1) في الحيوانات، مادة كيميائية تنظيمية تنتقل في الدم من أماكن انتاجها، عادة الغدة الصماء إلى أماكن أخرى، حيث تستجيب الخلايا المستهدفة إلى الإشارة التنظيمية. (2) في النباتات، مادة كيميائية يتم انتاجها في جزء واحد من النبات وتنتقل إلى أجزاء أخرى، حيث تعمل على الخلايا المستهدفة لتغيير وظائفها.

humus (hyū′-mus) Decomposing organic material found in topsoil.

الدبال مادة عضوية محللة موجودة في الأرض الزراعية.

hybrid An offspring of parents of two different species or of two different varieties of one species; an offspring of two parents that differ in one or more inherited traits; an individual that is heterozygous for one or more pairs of genes.

الهجين سلالة لأب من نوعين مختلفين أو تشكيلتين مختلفتين من نوع واحد؛ سلالة لأبوين مختلفين في صفة وراثية أو أكثر؛ فرد متخالف في زوج أو أكثر من الجينات.

hydrocarbon An organic compound composed only of the elements carbon and hydrogen.

الهيدروكربون مركب عضوي مؤلف فقط من عناصر الكربون والهيدروجين.

hydrogen bond A type of weak chemical bond formed when the partially positive hydrogen atom participating in a polar covalent bond in one molecule is attracted to the partially negative atom participating in a polar covalent bond in another molecule (or in another region of the same molecule).

الرابط الهيدروجيني نوع من الروابط الكيميائية الضعيفة التي تتشكل عندما تقوم ذرة الهيدروجين الإيجابية المشاركة في رابط تساهمي قطبي في أحد الجزيئات، بالارتباط جزئيا مع ذرة الهيدروجين السالبية المشاركة في رابط تساهمي قطبي في جزيء آخر (أو في مكان آخر في نفس الجزيء).

hydrolysis (hī-drol′-uh-sis) A chemical reaction that breaks bonds between two molecules by the addition of water; process by which polymers are broken down and an essential part of digestion.

حلمأة تفاعل كيميائي يعمل على تكسير الروابط بين جزيئين عن طريق إضافة الماء؛ عملية يتم خلالها تكسير البلمرات وتعتبر جزء ضروري في الهضم.

hydrophilic (hī′-drō-fil′-ik) "Water-loving"; pertaining to polar or charged molecules (or parts of molecules) that are soluble in water.

مسترطب "محب للماء" يتعلق بالجزيئات القطبية أو المشحونة (أو أجزاء من الجزيئات) التي تتحلل في الماء.

hydrophobic (hī′-drō-fō′-bik) "Water-fearing"; pertaining to nonpolar molecules (or parts of molecules) that do not dissolve in water.

فوبيا الماء "خوف من الماء" تتعلق بالجزيئات غير القطبية (أو أجزاء من الجزيئات) التي لا تتحلل في الماء.

hydroxyl group (hī-drok′-sil) A chemical group consisting of an oxygen atom bonded to a hydrogen atom.

مجموعة هيدروكسيل مجموعة كيميائية تتكون من ذرة أوكسجين مرتبطة بذرة هيدروجين.

hypothalamus (hī-pō-thal′-uh-mus) The master control center of the endocrine system, located in the ventral portion of the vertebrate forebrain. The hypothalamus functions in maintaining homeostasis, especially in coordinating the endocrine and nervous systems; secretes hormones of the posterior pituitary and releasing hormones that regulate the anterior pituitary.

الوطاء مركز التحكم الرئيسي للجهاز الصماوي، الذي يقع في الجزء البطني من الدماغ المقدم الفقاري. يعمل الوطاء في الحفاظ على الاستتباب، خاصة في تنسيق الجهاز الصماوي والجهاز العصبي؛ يفرز هرمونات النخامية الخلفية ويطلق الهرمونات التي تنظم النخامية الأمامية.

hypothesis (hī-poth′-uh-sis) (plural, **hypotheses**) A testable explanation for a set of observations based on the available data and guided by inductive reasoning.

الفرضية (الجمع **فرضيات**) تفسير تم اختباره لمجموعة من الملاحظات استنادا إلى البيانات المتاحة وتخضع لمنطق استقرائي.

hypotonic Referring to a solution that, when surrounding a cell, will cause the cell to take up water.

ناقص التوتر تشير إلى المحلول الذي عندما يحيط بالخلية، يتسبب في امتصاص الخلية للماء.

I

immune system An animal body's system of defenses against agents that cause disease.

جهاز المناعة الجهاز المسؤول عن الدفاع في جسم الحيوان ضد العوامل التي تسبب الأمراض.

incomplete dominance A type of inheritance in which the phenotype of a heterozygote (*Aa*) is intermediate between the phenotypes of the two types of homozygotes (*AA* and *aa*).

السيادة غير الكاملة نوع من الإرث يكون فيه النمط الظاهري للزيجوت متغايرة الألائل (Aa) وسيط بين نوعي الزيجوت متماثلة الألائل (AA و aa).

induction During embryonic development, the influence of one group of cells on an adjacent group of cells.

الحث أثناء التطور الجنيني، تأثير مجموعة واحدة من الخلايا على المجموعات المجاورة من الخلايا.

inductive reasoning A type of logic in which generalizations are based on a large number of specific observations.

المنطق الاستقرائي نوع من المنطق الذي تستند فيه التعميمات إلى عدد كبير من الملاحظات المحددة.

inferior vena cava (vē′-nuh kā′-vuh) A large vein that returns oxygen-poor blood to the heart from the lower, or posterior, part of the body. *See also* superior vena cava.

الوريد الأجوف السفلي وريد كبير يعيد الأوكسجين غير الغني بالدم إلى القلب من الجزء السفلي أو الخلفي من الجسم. انظر أيضا الوريد الأجوف العلوي.

infertility The inability to conceive after one year of regular, unprotected intercourse.

العقم عدم القدرة على الحمل بعد عام واحد من الجماع المنتظم غير المحمي.

ingestion The act of eating; the first main stage of food processing in animals.

الابتلاع عملية الأكل؛ المرحلة الرئيسية الأولى من عملية التمثيل الغذائي في الحيوانات.

innate behavior Behavior that is under strong genetic control and is performed in virtually the same way by all members of a species.

سلوك خلقي سلوك يخضع لتحكم جيني قوي ويتم إجراؤه بنفس الطريقة من قبل جميع الأعضاء من نفس النوع.

insulin A protein hormone, secreted by the islets of Langerhans in the pancreas, that lowers the level of glucose in the blood. It is antagonistic with glucagon.

الأنسولين هرمون بروتيني، يتم إفرازه عن طريق جزر اللانغرهانسي في البنكرياس؛ والذي يقلل مستويات الجلوكز في الدم. يعتبر الأنسولين مضاد للغلوكاغون.

integration The analysis and interpretation of sensory signals within neural processing centers of the central nervous system.

التكامل تحليل وتفسير للإشارات الحسية خلال المراكز العصبية للجهاز العصبي المركزي.

integumentary system (in-teg′-yū-ment-ter-ē) The organ system consisting of the skin and its derivatives, such as hair and nails in mammals. The integumentary system helps protect the body from drying out, mechanical injury, and infection.

النظام الجلدي النظام العضوي الذي يتكون من الجلد ومشتقاته مثل الشعر والأظافر في الثدييات. يساعد النظام الجلدي على وقاية الجسم من الجفاف والإصابات الميكانيكية والعدوى.

interferon (in′-ter-fer′-on) An innate defensive protein produced by virus-infected vertebrate cells and capable of helping other cells resist viruses.

الإنترفيرون بروتين خلقي دفاعي يتم إنتاجه عن طريق الخلايا الفقارية المصابة بالفيروس، يساعد الخلايا الأخرى على مقاومة الفيروسات.

intermediate One of the compounds that form between the initial reactant and the final product in a metabolic pathway, such as between glucose and pyruvate in glycolysis.

المركب المتوسط أحد المركبات التي تتكون بين المفاعل الأولي والمنتج النهائي في مسار استقلابي، كالذي يكون بين الجلوكوز والبَيرُوفات في عملية التحلل السكري.

intermediate filament An intermediate-sized protein fiber that is one of the three main kinds of fibers making up the cytoskeleton of eukaryotic cells. Intermediate filaments are ropelike, made of fibrous proteins.

خيط متوسط ألياف بروتينية متوسطة الحجم وتعد واحدة من الأنواع الرئيسية الثلاثة للألياف والتي تشكل هيكل الخلية حقيقية النواة. الخيوط المتوسطة تشبه الأحبال وهي مصنوعة من بروتينات ليفية.

internal fertilization Reproduction in which sperm are typically deposited in or near the female reproductive tract and fertilization occurs within the tract.

التخصيب الداخلي التوالد الذي يتم فيه وضع الحيوان المنوي في أو بالقرب من القناة التوالدية في الأنثى ويحدث الإخصاب في القناة.

internode The portion of a plant stem between two nodes.

الراجبة جزء من ساق النبات بين عقدتين.

interphase The period in the eukaryotic cell cycle when the cell is not actually dividing. Interphase constitutes the majority

of the time spent in the cell cycle. *See also* mitotic phase (M phase).

الطور البيني الفترة في دورة الخلية الحيوانية في حال عدم انقسام الخلية. الطور البيني يمثل غالبية الوقت المنقضي في دورة الخلية. انظر أيضا مرحلة الانقسام الفتيلي (مرحلة M).

interstitial fluid (in′-ter-stish′-ul) An aqueous solution that surrounds body cells and through which materials pass back and forth between the blood and the body tissues.

السائل الخلالي محلول مائي يحيط بخلية الجسم ومن خلاله تمر المواد للأمام والخلف بين الدم وأنسجة الجسم.

intestine The region of a digestive tract located between the gizzard or stomach and the anus and where chemical digestion and nutrient absorption usually occur.

الأمعاء منطقة من السبيل الهضمي تقع بين الحوصلة أو المعدة وفتحة الشرج حيث يحدث فيها الهضم الكيميائي وامتصاص المواد الغذائية.

invertebrate An animal that lacks a backbone.

اللافقاريات حيوان ينقصه العمود الفقري.

ion (ī-ōn) An atom or group of atoms that has gained or lost one or more electrons, thus acquiring a charge.

الأيون ذرة أو مجموعة من الذرات اكتسبت أو فقدت إلكترون أو أكثر، ومن تكتسب شحنات.

ionic bond (ī-ōn′-ik) A chemical bond resulting from the attraction between oppositely charged ions.

الرابط الأيوني رابط ينتج عن الانجذاب بين أيونات مشحونة بصورة عكسية.

isomers (ī′-sō-mers) Organic compounds with the same molecular formula but different structures and, therefore, different properties.

الأيسومرات مركبات عضوية بنفس التركيبة الجزيئية ولكن ببناء مختلف وليس صفات مختلفة.

isotope (ī′-sō-tōp) One of several atomic forms of an element, each with the same number of protons but a different number of neutrons.

النظير واحد من أشكال ذرية عديدة للعنصر، كل منها يحتوي على نفس عدد البروتونات وأعداد مختلفة من النيترونات.

K

kelp Large, multicellular brown algae that form undersea "forests."

الشبا طحالب بنية متعددة الخلايا تتكون تحت سطح الماء "الغابات".

kilocalorie (kcal) A quantity of heat equal to 1,000 calories. Used to measure the energy content of food, it is usually called a "Calorie."

كيلو كالوري كمية من الحرارة تعادل 1,000 كالوري. تستخدم لقياس محتويات الطاقة من الغذاء، تسمى عادة "الكالوري".

kinesis (kuh-nē′-sis) (plural, **kineses**) Random movement in response to a stimulus.

الحركة (الجمع حركات) حركة عشوائية في الاستجابة للمنبهات.

kinetic energy (kuh-net′-ik) The energy of motion; the energy of a mass of matter that is moving. Moving matter does work by imparting motion to other matter.

الطاقة الحركية طاقة الحركة؛ طاقة كتلة من المادة تتحرك. المادة المتحركة تعمل من خلال نقل الحركة إلى مواد أخرى.

kingdom In classification, the broad taxonomic category above phylum.

المملكة في التصنيف، الفئة التصنيفية العريضة فوق الشعبة.

L

labia majora (lā′-bē-uh muh-jor′-uh) A pair of outer thickened folds of skin that protect the female genital region.

الشفران الصغيران زوج من الطيات السميكة من الجلد والتي تحمي المنطقة التناسلية لدى الأنثى.

labia minora (lā′-bē-uh mi-nor′-uh) A pair of inner folds of skin, bordering and protecting the female genital region.

الشفران الصغيران زوج من الطيات السميكة من الجلد والتي تحمي المنطقة التناسلية لدى الأنثى.

lactic acid fermentation Glycolysis followed by the reduction of pyruvate to lactate, regenerating NAD^+.

تخمر الحمض اللاكتيكي تحلل متبوع بانخفاض البيروفات إلى اللاكتات، توليد NAD^+.

large intestine *See* colon.

الأمعاء الغليظة انظر القولون.

larva (lar′-vuh) (plural, **larvae**) A free-living, sexually immature form in some animal life cycles that may differ from the adult in morphology, nutrition, and habitat.

اليرقة (الجمع يرقات) شكل حر غير ناضج جنسيا في دورات الحياة في بعض الحيوانات والذي ربما يختلف من البالغين في المورفولوجيا والتغذية والموئل.

larynx (lār′-inks) The upper portion of the respiratory tract containing the vocal cords; also called the voice box.

الحنجرة الجزء العلوي من السبيل التنفسي والذي يحتوي على الأحبال الصوتية، وتسمى أيضا صندوق الصوت.

law of segregation A general rule in inheritance (originally formulated by Gregor Mendel) that individuals have two alleles for each gene and that when gametes form by meiosis, the two alleles separate, each resulting gamete ending up with only one allele of each gene; also known as Mendel's first law of inheritance.

قانون العزل قاعدة عامة في الوراثة (تم صياغتها وراثيا عن طريق جريجور مندل) والتي تتألف فرديا من أليلين لكل جين وعندما تتكون الأعراس عن طريق الانتصاف، ينفصل الأليلان، وكل واحد منهما ينتج عنه عرس ينتهي بأليل واحدة لكل جين؛ تعرف أيضا بقانون مندل الأول للوراثة.

leaf The main site of photosynthesis in a plant; typically consists of a flattened blade and a stalk (petiole) that joins the leaf to the stem.

الورقة المكان الرئيسي للتمثيل الضوئي في النبات؛ تتألف من لوح مسطح وساق (سويقة) تربط الورقة بالجذع.

learning Modification of behavior as a result of specific experiences.

التعلم تغير السلوك نتيجة لخبرة معينة.

lichen (lī′-ken) A close association between a fungus and an alga or between a fungus and a cyanobacterium, some of which are known to be beneficial to both partners.

الحزاز ارتباط وثيق بين الفطر والطحلب أو بين الفطر والبكتيريا الزرقاء، يعرف بعضٌ منها على أنه مفيد لكلا الشريكين.

life cycle The entire sequence of stages in the life of an organism, from the adults of one generation to the adults of the next.

دورة الحياة التسلسل الكامل لمراحل حياة الكائن الحي، من البالغين في جيل معين إلى البالغين في الجيل التالي.

life table A listing of survivals and deaths in a population in a particular time period and predictions of how long, on average, an individual of a given age will live.

جدول مجريات الحياة سلسلة من الأحياء والوفيات في السكان في فترة زمنية معينة وتوقعات حول عمر الفرد في المتوسط.

ligament A type of fibrous connective tissue that joins bones together at joints.

الرابط نوع من الأنسجة الليفية الموصلة التي تربط العظام في منطقة المفاصل.

light microscope (LM) An optical instrument with lenses that refract (bend) visible light to magnify images and project them into a viewer's eye or onto photographic film.

المجهر الضوئي (LM) آلة بصرية بعدسات تكسر شعاع الضوء المرئي التي تكبر الصور وتصورها في عين الرائي أو في شريط فوتوغرافي.

light reactions The first of two stages in photosynthesis; the steps in which solar energy is absorbed and converted to chemical energy in the form of ATP and NADPH. The light reactions power the sugar-producing Calvin cycle but produce no sugar themselves.

التفاعلات الضوئية أول مرحلتين في عملية التمثيل الضوئي؛ الخطوات التي يتم فيها امتصاص الطاقة الشمسية وتحويلها إلى طاقة كيميائية في صورة ATP و NADPH. تدعم التفاعلات الضوئية دورة كالفين المنتجة للسكر ولكنها لا تنتج السكر نفسه.

GLOSSARY

limbic system (lim′-bik) A functional unit of several integrating and relay centers located deep in the human forebrain; interacts with the cerebral cortex in creating emotions and storing memories.

الجهاز الحوفي وحدة وظيفية بمراكز متعددة متكاملة تقع في منطقة عميقة من الدماغ المقدم؛ تتفاعل مع قشرة المخ في خلق المشاعر وتسجيل الذكريات.

lipid An organic compound consisting mainly of carbon and hydrogen atoms linked by nonpolar convalent bonds, making the compound mostly hydrophobic. Lipids include fats, phospholipids, and steroids and are insoluble in water.

الشحم مركب عضوي يتكون بصورة رئيسية من ذرات كربون وهيدروجين مرتبطة بروابط تساهمية غير قطبية، مما يجعل المركب كاره للماء. يشتمل الشحم على الدهون والمواد الكارهة للماء والستيرويد وجميعها لا تذوب في الماء.

liver The largest organ in the vertebrate body. The liver performs diverse functions, such as producing bile, preparing nitrogenous wastes for disposal, and detoxifying poisonous chemicals in the blood.

الكبد أكبر عضو في الجسم الفقاري. يقوم الكبد بوظائف عديدة، مثل إنتاج الصفراء وإعداد الفضلات النيتروجينية للتخلص منها وإزالة السمية من المواد الكيميائية السامة في الدم.

locus (plural, **loci**) The particular site where a gene is found on a chromosome. Homologous chromosomes have corresponding gene loci.

الموضع (الجمع **مواضع**) المكان الخاص الذي يوجد فيه الجين على الكروموسوم. الكروموسومات المتطابقة بها مواضع جينات متصلة.

loose connective tissue The most widespread connective tissue in the vertebrate body. It binds epithelia to underlying tissues and functions as packing material, holding organs in place.

النسيج الضام الرخو أكثر الأنسجة الضامة انتشارا في الجسم الفقاري. يربط الظهاري بالأنسجة المبطنة ويعمل بمثابة مادة تجميع، تضع الأعضاء في مكانها.

lung An infolded respiratory surface of terrestrial vertebrates that connects to the atmosphere by narrow tubes.

الرئة سطح تنفسي ملفوف للفقاريات البرية التي ترتبط بالغلاف الجوي عن طريق أنابيب ضيقة.

lymphatic system (lim-fat′-ik) The vertebrate organ system through which lymph circulates; includes lymph vessels, lymph nodes, and the spleen. The lymphatic system helps remove toxins and pathogens from the blood and interstitial fluid and returns fluid and solutes from the interstitial fluid to the circulatory system.

الجهاز اللمفاوي نظام الأعضاء الفقارية والذي من خلاله تدور اللمفات؛ يشتمل على أوعية لمفية وعقد لمفية والطحال. يساعد النظام اللمفي على إزالة الذيفانات والممرضات من الدم والسائل الخلالي ويعيد السائل ويذوب من السائل الخلالي إلى النظام الدوراني.

lymphocyte (lim′-fuh-sīt) A type of white blood cell that is chiefly responsible for the acquired immune response and is found mostly in the lymphatic system. *See* B cell; T cell.

اللمفاوية نوع من خلايا الدم البيضاء المسؤولة بصورة رئيسية عن استجابة المناعة المكتسبة وتوجد غالبا في النظام اللمفي. انظر أيضا خلية T.

lysosome (lī-sō-sōm) A digestive organelle in eukaryotic cells; contains hydrolytic enzymes that digest engulfed food or damaged organelles.

اليحلول عضيات هضمية في الخلايا الحيوانية؛ تحتوي على إنزيمات محللة تهضم الأطعمة المبلوعة أو العضيات التالفة.

M

macromolecule A giant molecule formed by the joining of smaller molecules, usually by a dehydration reaction: a protein, carbohydrate, or nucleic acid.

جزيء ضم جزئ عملاق يتكون عن طريق ربط جزيئات صغيرة، يكون عادة من خلال تفاعلات جافة: البروتين أو الكربوهيدرات أو الحمض النووي.

macronutrient A chemical substance that an organism must obtain in relatively large amounts. *See also* micronutrient.

المغذيات كبيرة المقدار مادة كيميائية يجب أن يحصل عليها الكائن الحي بكميات كبيرة بصورة نسبية. انظر أيضا المغذي زهيد المقدار.

malnutrition A failure to obtain adequate nutrition.

سوء التغذية الإخفاق في الحصول على التغذية الملائمة.

mammal Member of a clade of amniotes that possess mammary glands and hair.

الثدييات عضو من مجموعة متعددة الأفرع من الحيوانات السلوية التي يكون لديها غدد ثديية وشعر.

mass number The sum of the number of protons and neutrons in an atom's nucleus.

العدد الكتلي مجموع أعداد البروتونات والنيوترونات في جزيء الذرة.

matter Anything that occupies space and has mass.

المادة أي شيء يحتل مكان وله كتلة.

meiosis (mī-ō′-sis) In a sexually reproducing organism, the division of a single diploid nucleus into four haploid daughter nuclei. Meiosis and cytokinesis produce haploid gametes from diploid cells in the reproductive organs of the parents.

الانتصاف في الكائنات المتوالدة جنسيا، تقسيم النواة الضعفانية الفردية إلى أربعة نوي وليدة فردانية. ينتج الانتصاف والتشطر أعراسًا من الخلايا الضعفانية في الأعضاء المتوالدة من الآباء.

memory The ability to store and retrieve information. *See also* long-term memory; short-term memory.

الذاكرة القدرة على تخزين واسترجاع المعلومات.

mesoderm (mez′-ō-derm) The middle layer of the three embryonic cell layers in a gastrula. The mesoderm gives rise to muscles, bones, the dermis of the skin, and most other organs in the adult.

الأديم المتوسط الطبقة المتوسطة من طبقات الخلايا المضغية الثلاثة. الأديم المتوسط يؤدي إلى تقوية العضلات والعظام وأدمة الجلد وجميع الأعضاء الأخرى لدى البالغين.

mesophyll (mes′-ō-fil) The green tissue in the interior of a leaf; a leaf's ground tissue system; the main site of photosynthesis.

نسيج الورقة المتوسط النسيج الأخضر داخل الورقة؛ نظام الأنسجة الأرضية للورقة؛ الموقع الرئيسي للتمثيل الضوئي.

metabolic pathway A series of chemical reactions that either builds a complex molecule or breaks down a complex molecule into simpler compounds.

السبيل الأيضي سلسلة من التفاعلات الكيميائية التي إما تبني جزيئًا مركبًا أو تكسر جزيئًا مركبًا إلى مركبات أكثر بساطة.

metabolic rate The total amount of energy an animal uses in a unit of time.

المعدل الأيضي إجمالي كمية الطاقة التي يستخدمها الحيوان في وحدة من الزمن.

metabolism The totality of an organism's chemical reactions.

الأيض إجمالي التفاعلات الكيميائية للكائن الحي.

metamorphosis (met′-uh-mōr′-fuh-sis) The transformation of a larva into an adult. *See* complete metamorphosis; incomplete metamorphosis.

الاستحالة تحول اليرقة في البالغين.

metaphase (met′-eh-fāz) The third stage of mitosis, during which all the cell's duplicated chromosomes are lined up at an imaginary plane equidistant between the poles of the mitotic spindle.

الطور التالي في انقسام الخلية المرحلة الثالثة في الانقسام الفتيلي، التي يتم خلالها وضع جميع الكروموسومات المكررة في الخلية في مستوى تخيلي متساوي البعد بين أقطاب مغزل الانقسام التفتلي.

methyl group A chemical group consisting of a carbon atom bonded to three hydrogen atoms.

مجموعة الميثيل مجموعة كيميائية تتكون من ذرة كربون مرتبطة مع ثلاث ذرات هيدروجين.

microfilament The thinnest of the three main kinds of protein fibers making up the cytoskeleton of a eukaryotic cell; a solid, helical rod composed of the globular protein actin.

الخيط أرفع نوع من ثلاثة أنواع رئيسية من ألياف البروتينات والتي تكون هيكل الخلية في الخلية الحيوانية؛ قضيب حلزوني صلب مؤلف من أكتين بروتين كروي.

micrograph A photograph taken through a microscope.

الصورة المجهرية صورة فوتوغرافية عبر المجهر.

micronutrient An element that an organism needs in very small amounts and that functions as a component or cofactor of enzymes. *See also* macronutrient.

المغذيات زهيدة المقدار عنصر يحتاجه الكائن الحي بكميات قليلة للغاية والذي يعمل كمكون أو عنصر مساعد للإنزيمات. انظر أيضا مغذيات كبيرة المقدار.

microtubule The thickest of the three main kinds of fibers making up the cytoskeleton of a eukaryotic cell; a hollow tube made of globular proteins called tubulins; found in cilia and flagella.

الأنيبيب أسمك نوع من ثلاثة أنواع رئيسية من الألياف والتي تكون هيكل الخلية في الخلية الحيوانية؛ أنبوب أجوف مصنوع من بروتينات كروية تسمى صلب مؤلف من أكتين بروتين كروي يسمى توبولين؛ موجود في الأهداب والسياط.

mineral In nutrition, a simple inorganic nutrient that an organism requires in small amounts for proper body functioning.

المعدن في التغذية، مادة غذائية غير عضوية يحتاجها الكائن الحي بكميات صغيرة لتشغيل وظائف الجسم بصورة سليمة.

mitochondrial matrix The compartment of the mitochondrion enclosed by the inner membrane and containing enzymes and substrates for the citric acid cycle.

مصفوفة المتقدرة مكان في المتقدرة محاط بالغشاء الداخلي ويحتوي على إنزيمات وركائز لدورة حمض الستريك.

mitochondrion (mī′-tō-kon′-drē-on) (plural, **mitochondria**) An organelle in eukaryotic cells where cellular respiration occurs. Enclosed by two membranes, it is where most of the cell's ATP is made.

المتقدرة (الجمع **متقدرات**) عضيات في الخلايا الحيوانية يحدث فيها التنفس الخلوي. محاطة بغشائين، المكان الذي يتم فيه تكوين معظم ATP للخلايا.

mitosis (mī′-tō-sis) The division of a single nucleus into two genetically identical nuclei. Mitosis and cytokinesis make up the mitotic (M) phase of the cell cycle.

التفتل انقسام نواة مفردة إلى نواتين متماثلتين وراثيا: التفتل والحرائك الخلوية تشكل المرحلة التفتلية (M) لدورة الخلية.

mitotic phase (M phase) The part of the cell cycle when the nucleus divides (via mitosis), its chromosomes are distributed to the daughter nuclei, and the cytoplasm divides (via cytokinesis), producing two daughter cells.

المرحلة التفتلية جزء من دورة الخلية عندما تنقسم النواة (عبر التفتل)، يتم توزيع الكروموسومات على النواة الوليدة، الهيولي ينقسم (عبر الحرائك الخلوية)، منتجا خليتين وليدتين.

mitotic spindle A football-shaped structure formed of microtubules and associated proteins that is involved in the movement of chromosomes during mitosis and meiosis.

مغزل الانقسام التفتلي بناء على شكل كرة قدم مكون من أنيبيبات وبروتينات مرتبطة تدخل في حركة الكروموسومات أثناء التفتل والانقسام.

mold A rapidly growing fungus that reproduces asexually by producing spores.

العفن فطريات تنمو بصورة سريعة تتكاثر لا جنسيا عن طريق إنتاج أبواغ.

molecular biology The study of the molecular basis of genes and gene expression; molecular genetics.

البيولوجيا الجزيئية دراسة الأساس الجزيئي للجينات والتعبير الجيني؛ الهندسة الوراثية الجزيئية.

molecule Two or more atoms held together by covalent bonds.

الجزيء ذرتان أو أكثر مرتبطتان بروابط تساهمية.

monocot (mon′-ō-kot) A flowering plant whose embryos have a single seed leaf, or cotyledon.

عارية البذور نبات زهري أجنتها لها ورقة بذرة فردية، أو فلقة.

monohybrid cross An experimental mating of individuals differing in a single character.

الهجين أحادي الخلية تزاوج تجريبي لأفراد مختلفين في خاصية مفردة.

monomer (mon′-uh-mer) The subunit that serves as a building block of a polymer.

المونومر الوحدة الفرعية التي تعمل كحاجز بنائي للبلمر.

monosaccharide (mon′-ō-sak′-uh-rīd) The simplest carbohydrate; a simple sugar with a molecular formula that is generally some multiple of CH_2O. Monosaccharides are the monomers of disaccharides and polysaccharides.

أحادي السكاريد أبسط كربوهيدرات؛ سكر بسيط بتركيبة جزيئية والذي يعتبر صورة متعددة من CH_2O . أحادي السكاريد هي المونومر وعديد السكاريد.

mouth An opening through which food is taken into an animal's body, synonymous with oral cavity.

الفم مرحلة يدخل خلالها الطعام في جسم الإنسان، مرادف للتجويف الفموي.

muscle tissue Tissue consisting of long muscle cells that can contract, either on its own or when stimulated by nerve impulses; the most abundant tissue in a typical animal. *See* skeletal muscle; cardiac muscle; smooth muscle.

الأنسجة العضلية أنسجة تحتوي على خلايا عضلية طويلة يمكن أن تنبسط، إما بصورتها الذاتية أو عندما تنبه بمنبهات عصبية؛ الأنسجة الأكثر وفرة في الحيوانات النمطية. انظر العضلات الهيكلية والعضلات القلبية والعضلات الملساء.

muscular system The organ system that includes all the skeletal muscles in the body. (Cardiac muscle and smooth muscle are components of other organ systems.)

النظام العضلي النظام العضوي الذي يشتمل على جميع العضلات الهيكلية في الجسم. (العضلات القلبية والعضلات الملساء تعتبر مكونات من أنظمة أعضاء أخرى.

mutagen (myū′-tuh-jen) A chemical or physical agent that interacts with DNA and causes a mutation.

المطفر عنصر كيميائي أو فيزيائي يتفاعل مع الدنا ويسبب الطفرة.

mutation A change in the nucleotide sequence of an organism's DNA; the ultimate source of genetic diversity. A mutation also can occur in the DNA or RNA of a virus.

الطفرة تغير في التسلسل النوكليوتيدي للدنا في الكائن الحي؛ المصدر المثالي للتنوع الوراثي. يمكن أن تحدث الطفرة أيضا في الدنا أو الرنا للفيروس.

mycosis A general term for a fungal infection.

الفطار مصطلح عام للعدوى الفطرية.

myosin A type of protein filament that interacts with actin filaments to cause cell contraction.

الميوزين نوع من خيط البروتين الذي يتفاعل مع خيوط الأكتين التي تسبب انبساط الخلية.

N

NAD$^+$ Nicotinamide adenine dinucleotide; a coenzyme that can accept electrons during the redox reactions of cellular metabolism. The plus sign indicates that the molecule is oxidized and ready to pick up hydrogens; the reduced, hydrogen (electron)-carrying form is NADH.

NAD$^+$ ثنائي نوكليوتيد الأدنين والنيكوتيناميد؛ إنزيم مساعد يقبل الإلكترونات أثناء تفاعلات الأكسدة والاختزال للأيض الخلوي. علامة زائد تشير إلى أن الجزيء مؤكسد وجاهز لالتقاط ذرات الهيدروجين؛ شكل ذرة الهيدروجين المختزلة الحاملة للإلكترون هو NADH.

NADP$^+$ Nicotinamide adenine dinucleotide phosphate, an electron acceptor that, as NADPH, temporarily stores energized electrons produced during the light reactions.

NADP$^+$ فوسفات ثنائي نيوكليداتيد الأدينينو النيوكوتيناميد، مستقبل الإلكترون، مثل NADPH، يخزن الإلكترونات المشحونة بصورة مؤقتة والتي يتم انتاجها أثناء التفاعلات الضوئية.

negative feedback A primary mechanism of homeostasis, whereby a change in a physiological variable triggers a response that counteracts the initial change. Negative feedback is a common control mechanism in which a chemical reaction, metabolic pathway, or hormone-secreting gland is inhibited by the products of the reaction, pathway, or gland.

GLOSSARY

As the concentration of the products builds up, the product molecules themselves inhibit the process that produced them.

الارتجاع السلبي آلية رئيسية للاستتباب، حيث يؤدي أي تغير في المتغير النفسي إلى استجابة تتفاعل ضد التغيير المبدئي. الارتجاع السلبي عبارة عن آلية تحكم شائعة تثبط فيها التفاعلات الكيميائية والسبيل الأيضي والغدة المفرزة للهرمون عن طريق منتجات التفاعل، أو السبيل أو الغدة. وكلما زاد تركيز المنتجات، تثبط جزيئات المنتجات ذاتها العملية التي تنتجها.

negative pressure breathing A breathing system in which air is pulled into the lungs.

تنفس الضغط السالب نظام تنفس يتم فيه سحب الهواء إلى الرئتين.

nerve A cable-like bundle of neurons tightly wrapped in connective tissue.

العصب مجموعة من الأعصاب تشبه الكابل ملفوفة بقوة في النسيج الضام.

nervous system The organ system that forms a communication and coordination network between all parts of an animal's body.

النظام العصبي النظام العضوي الذي يشكل شبكة اتصال وتنسيق بين جميع أجزاء جسم الحيوان.

nervous tissue Tissue made up of neurons and supportive cells.

النسيج العصبي نسيج مصنوع من أعصاب وخلايا داعمة.

neural tube (nyūr′-ul) An embryonic cylinder that develops from the ectoderm after gastrulation and gives rise to the brain and spinal cord.

الأنبوب العصبي أسطوانة جنينية تتطور من الأديم الظاهر بعد تكون المعيدة مما يساعد على نمو الدماغ والحبل الشوكي.

neuron (nyūr′-on) A nerve cell; the fundamental structural and functional unit of the nervous system, specialized for carrying signals from one location in the body to another.

العصبون خلية عصبية؛ الوحدة الأساسية والهيكلية والوظيفية للجهاز العصبي، والمتخصصة في حمل الإشارات من موقع إلى آخر في الجسم.

neurotransmitter A chemical messenger that carries information from a transmitting neuron to a receiving cell, either another neuron or an effector cell.

الناقل العصبي مراسل كيميائي يحمل المعلومات من العصبون الناقل إلى خلية متلقية، إما عصبون آخر أو خلية مؤثرة.

neutron A subatomic particle having no electrical charge, found in the nucleus of an atom.

النيوترون جسيم شبه ذري لا يحتوي على شحنات كهربائية، موجود في نواة الذرة.

nitrogen fixation The conversion of atmospheric nitrogen (N_2) to nitrogen compounds (NH_4^+, NO_3^-) that plants can absorb and use.

تثبيت النيتروجين تحول النيتروجين الغلافي (N_2) المركبات نيتروجين (NH_4^+, NO_3^-) التي تستطيع النباتات امتصاصها واستخدامها.

node The point of attachment of a leaf on a stem.

العقدة نقطة الاتصال بين الورقة والجذع.

nonpolar covalent bond A covalent bond in which electrons are shared equally between two atoms of similar electronegativity.

الرابط التساهمي غير القطبي رابط تساهمي تشترك فيه الإلكترونات بصورة متساوية بين ذرتين من كهربية سلبية متشابهة.

nuclear envelope A double membrane that encloses the nucleus, perforated with pores that regulate traffic with the cytoplasm.

غلاف النواة غشاء مزدوج يغلف النواة، مثقوب بمسام نووية تنظم الحركة مع الهيولي.

nucleic acid (nū-klā′-ik) A polymer consisting of many nucleotide monomers; serves as a blueprint for proteins and, through the actions of proteins, for all cellular structures and activities. The two types of nucleic acids are DNA and RNA

الحمض النووي بولمر يتكون من مونومرات عديدة من النوكليوتيد؛ يعمل كمخطط أولي للبروتينات ومن خلال تفاعلات البروتينات، لجميع البنائات والأنشطة الخلوية. كلا النوعين من الأحماض النووية هما الدنا والرنا.

nucleoid (nū′-klē-oyd) A dense region of DNA in a prokaryotic cell.

نوواني منطقة كثيفة من الدنا في الخلية بدائية النواة.

nucleolus (nū-klē′-ō-lus) A structure within the nucleus where ribosomal RNA is made and assembled with proteins imported from the cytoplasm to make ribosomal subunits.

النوية بناء داخل النواة حيث يتم فيه عمل الرنا الريباسي وتجميعه مع البروتينات المستوردة من الهيولي لعمل الوحدات الفرعية الريباسية.

nucleotide (nū′-klē-ō-tīd) A building block of nucleic acids, consisting of a five-carbon sugar covalently bonded to a nitrogenous base and one or more phosphate groups.

النوكليوتيد حاجز بنائي من الأحماض النووية، تتكون من سكر خماسي الكربون مرتبط تساهميا مع قاعدة نيتروجينية ومجموعة أو أكثر من مجموعات الفوسفات.

nucleus (plural, **nuclei**) (1) An atom's central core, containing protons and neutrons. (2) The genetic control center of a eukaryotic cell.

النواة (**الجمع نوي**) (1) اللب المركزي للذرة والذي يحتوي على بروتونات ونيوترونات. (2) مركز التحكم الوراثي في الخلية الحيوانية.

O

obesity The excessive accumulation of fat in the body.

السمنة تراكم الدهون بصورة مفرطة في الجسم.

ocean acidification Decreasing pH of ocean waters due to absorption of excess atmospheric CO_2 from the burning of fossil fuels.

تحميض المحيط خفض pH من ماء المحيط بسبب امتصاص كميات كبيرة من ثاني أكسيد الكربون من احتراق الوقود الأحفوري.

omnivore An animal that eats animals as well as plants or algae.

القارت حيوان يأكل الحيوانات والنباتات والطحالب.

oogenesis (ō′-uh-jen′-uh-sis) The development of mature egg cells.

تكون البيضة تطور خلايا البيض الناضجة.

open circulatory system A circulatory system in which blood is pumped through open-ended vessels and bathes the tissues and organs directly. In an animal with an open circulatory system, blood and interstitial fluid are one and the same.

النظام الدوراني المفتوح يتم فيه ضخ الدم من خلال أوعية ذات نهايات مفتوحة وتصل إلى الأنسجة والأعضاء مباشرة. في الحيوان ذي الجهاز الدوري المفتوح، يكون الدم والسائل الخلالي عبارة عن شيء واحد.

opposable thumb An arrangement of the fingers such that the thumb can touch the ventral surface of the fingertips of all four fingers.

الإبهام المعاكس ترتيب للأصابع يستطيع فيها أصبع الإبهام لمس السطح البطني لأطراف جميع الأصابع الأربع.

oral cavity The mouth of an animal.

التجويف الفموي فم الحيوان.

order In Linnaean classification, the taxonomic category above family.

الترتيب التصنيف الحيوي، الفئة التصنيفية فوق الأسرة.

organ A specialized structure composed of several different types of tissues that together perform specific funstions.

العضو بناء متخصص مؤلف من أنواع عديدة مختلفة من الأنسجة التي تقوم بوظائف محددة مع بعضها البعض.

organ system A group of organs that work together in performing vital body functions.

النظام العضوي مجموعة من الأعضاء التي تعمل مع بعضها بعضًا لإجراء وظائف الجسم الضرورية.

organelle (ōr-guh-nel′) A membrane-enclosed structure with a specialized function within a cell.

العضية بناء مغلف بالأغشية له وظائف خاصة في الخلية.

organic compound A chemical compound containing the element carbon and usually the element hydrogen.

المركب العضوي مركب كيميائي يحتوى على عنصر الكربون وغالبا عنصر الهيدروجين.

organism An individual living thing, such as a bacterium, fungus, protist, plant, or animal.

الكائن الحي شيء يعيش فرديا مثل البكتيريا والفطريات والأولانيات والنبات والحيوان.

orgasm A series of rhythmic, involuntary contractions of the reproductive structures.

النشوة الجنسية سلسة من الانقباضات الإيقاعية اللاإرادية في الهياكل الإنجابية.

osmosis (oz-mō′-sis) The diffusion of water across a selectively permeable membrane.

التناضح انتشار الماء عبر غشاء منفذ انتقائي.

ovary (1) In animals, the female gonad, which produces egg cells and reproductive hormones. (2) In flowering plants, the basal portion of a carpel in which the egg-containing ovules develop.

المبيض (1) في الحيوان، الغدد التناسلية الأنثوية التي تنتج الخلايا البيضية و الهرمونات التناسلية. (2) في النباتات المزهرة الجزء القاعدي من الخباء حيث تنمو البيضة المحتوية على البويضة.

oviduct (ō′-vuh-dukt) The tube that conveys egg cells away from an ovary; also called a fallopian tube. In humans, the oviduct is the normal site of fertilization.

قناة البيض القناة التي تنقل الخلايا البيضية بعيدا عن المبيض وأيضا تسمى قناة فالوب. في الإنسان قناة البيض هي المكان الطبيعي للتخصيب.

ovulation (ah′-vyū-lā′-shun) The release of an egg cell from an ovarian follicle.

التبويض خروج الخلية البيضية من الجريب المبيضي.

oxidation The loss of electrons from a substance involved in a redox reaction; always accompanies reduction.

الأكسدة فقدان الإلكترونات من المادة التي تدخل في تفاعلات الأكسدة والاختزال؛ يصاحبه انخفاض.

oxidative phosphorylation (fos′-fōr-uh-lā′-shun) The production of ATP using energy derived from the redox reactions of an electron transport chain; the third major stage of cellular respiration.

فسفتة أكسيدية إنتاج ATP باستخدام الطاقة المنشقة من تفاعلات الأكسدة والاختزال الخاصة بسلسلة نقل الإلكترون؛ المرحلة الرئيسية الثالثة في التنفس الخلوي.

ozone layer The layer of ozone (O_3) in the upper atmosphere that protects life on Earth from the harmful ultraviolet rays in sunlight.

طبقة الأوزون طبقة الأوزون (O3) في الغلاف الجوي العلوي الذي يحمي الحياة على الأرض من الأشعة الفوق البنفسجية الضارة في ضوء الشمس.

P

P generation The parent individuals from which offspring are derived in studies of inheritance; P stands for parental.

جيل P الفرد الأبوي الذي تنشق منه السلالة في دراسات الوراثة؛ P تشير إلى الأبوي.

pancreas (pan′-krē-us) A gland with dual functions: The digestive portion secretes digestive enzymes and an alkaline solution into the small intestine via a duct. The endocrine portion secretes the hormones insulin and glucagon into the blood.

البنكرياس غدة لها وظيفتان: البروتين الهضمي يفرز إنزيمات و محلولًا قلويًا في الأمعاء الدقيقة عبر قناة. الجزء الغددي الصماء يفرز هرمون الإنسولين والجلوكاجون.

parenchyma cell (puh-ren′-kim-uh) In plants, a relatively unspecialized cell with a thin primary wall and no secondary wall; functions in photosynthesis, food storage, and aerobic respiration and may differentiate into other cell types.

الخلية المتنية في النباتات، خلية غير مخصصة نسبيًا بها جدار رقيق ولا يوجد بها جدار ثانوي؛ الوظائف في التمثيل الضوئي، تخزين الأغذية، التنفس الهوائي ويمكن تقسيمها إلى أنواع خلايا أخرى.

parsimony (par′-suh-mō′-nē) In scientific studies, the search for the least complex explanation for an observed phenomenon.

التقتير في الدراسات العلمية، البحث عن أقل شرح تعقيدا لظاهرة تم ملاحظتها.

partial pressure The pressure exerted by a particular gas in a mixture of gases; a measure of the relative amount of a gas.

الضغط الجزئي الضغط الذي يحدث بسبب نوع معين من الغاز في خليط من الغازات؛ وحدة قياس للكمية النسبية للغاز.

passive transport The diffusion of a substance across a biological membrane, with no expenditure of energy.

النقل السلبي انتشار المواد عبر الأغشية الحيوية، دون فقد أي طاقة.

pathogen An agent, such as a virus, bacteria, or fungus, that causes disease.

الممرض عنصر، مثل الفيروس أو البكتيريا أو الفطريات التي تسبب الأمراض.

pattern formation During embryonic development, the emergence of a body form with specialized organs and tissues in the right places.

تكون القالب أثناء التطور الجنيني، ظهور شكل الجسم به أعضاء محددة وأنسجة في الأماكن الصحيحة.

penis The copulatory structure of male mammals.

العضو الذكري بناء تناسلي في ذكور الثدييات.

peptide bond The covalent bond between two amino acid units in a polypeptide, formed by a dehydration reaction.

الرابط الببتيدي الرابط التساهمي بين وحدتين حمض أميني في عديد الببتيد، الذي يتشكل من خلال تفاعلات الجفاف.

peristalsis (per′-uh-stal′-sis) Rhythmic waves of contraction of smooth muscles. Peristalsis propels food through a digestive tract and also enables many animals, such as earthworms, to crawl.

التمعج موجات إيقاعية من انقباض العضلات الملساء. يعمل التمعج على طرد الطعام خلال السبيل الهضمي وكذلك تمكين العديد من الحيوانات، مثل دودة الأرض من الزحف.

peroxisome An organelle containing enzymes that transfer hydrogen atoms from various substrates to oxygen, producing and then degrading hydrogen peroxide.

العضية تتكون من الإنزيمات التي تنقل ذرات الهيدروجين من ركائز مختلفةإلى الأكسجين، تنتج ثم بعد ذلك تحلل فوق أكسيد الهيدروجين.

petal A modified leaf of a flowering plant. Petals are the often colorful parts of a flower that advertise it to pollinators.

البتلة ورقه معدلة من النباتات المزهرة. البتلات غالبا تكون الأجزاء الملونة من الزهرة والتي تعلن عنها للملقحات.

pH scale A measure of the relative acidity of a solution, ranging in value from 0 (most acidic) to 14 (most basic). The letters pH stand for potential hydrogen and refer to the concentration of hydrogen ions (H^+).

مقياس درجة الحموضة PH مقياس الحموضة النسبية للمحلول، وتتراوح قيمته بين 0 (الأكثر حموضة) الى 14 (الأكثر قاعدية). تشير الحروف pH إلى الهيدروجين المحتمل وتشير إلى تركيز أيونات الهيدروجين (H^+).

phage (fāj) *See* bacteriophage.

الفج انظر العاثية.

pharynx (fār′-inks) The organ in a digestive tract that receives food from the oral cavity; in terrestrial vertebrates, the throat region where the air and food passages cross.

البلعوم عضو في القناة الهضمية والذى يستقبل الطعام من التجويف الفموى، فى الفقاريات الأرضية؛ منطقة الحلق حيث يمر الطعام والهواء.

phenotype (fē′-nō-tīp) The expressed traits of an organism.

النمط الظاهري الخصائص الظاهرة للكائن الحى.

phloem (flō′-um) The portion of a plant's vascular tissue system that transports sugars and other organic nutrients from leaves or storage tissues to other parts of the plant.

اللحاء جزء من نظام الأنسجة الوعائية للنبات والذى ينقل السكريات وغيرها من المواد الغذائية العضوية من الأوراق أو أنسجة التخزين الى أجزاء النبات الأخرى.

phosphate group (fos′-fāt) A chemical group consisting of a phosphorus atom bonded to four oxygen atoms.

مجموعة الفوسفات مجموعة كيميائية تتكون من ذرة فوسفورية مرتبطة مع أربع ذرات أوكسجين.

phospholipid (fos′-fō-lip′-id) A lipid made up of glycerol joined to two fatty acids and a phosphate group, giving the molecule two nonpolar hydrophobic tails and a polar hydrophilic head. Phospholipids form bilayers that function as biological membranes.

شحمي فوسفوري شحم مصنوع من غليسيرول مرتبط بحمضين دهنيين ومجموعة فوسفات، مما يمنح الجزيء ذيلين غير قطبيين كارهين للماء ورأس كاره للماء. تشكل الجزيئات الشحمية الفوسفورية طبقات ثنائية تعمل كأغشية حيوية.

photon (fō′-ton) A fixed quantity of light energy. The shorter the wavelength of light, the greater the energy of a photon.

الفوتون كمية ثابتة من الطاقة. كلما كان طول موجة الضوء أقصر، كلما زادت طاقة الفوتون.

photosynthesis (fō′-tō-sin′-thuh-sis) The process by which plants, autotrophic protists, and some bacteria use light energy to make sugars and other organic food molecules from carbon dioxide and water.

التمثيل الضوئي العملية التي تستخدم من خلالها النباتات وأحاديات الخلايا ذاتية التغذية وبعض أنواع البكتيريا الطاقة الضوئية لتكوين السكر وغيرها من جزيئات الطعام العضوية من ثاني أكسيد الكربون والماء.

photosystem A light-capturing unit of a chloroplast's thylakoid membrane, consisting of a reaction-center complex surrounded by numerous light-harvesting complexes.

النظام الضوئي وحدة لاقطة للضوء من غشاء صانعة الكلوروفيل وغشاء التيلاكويدات، التي تتكون من مركب مركزي التفاعل محاط بمركبات حاصدة للضوء عديدة.

phylum (fī′-lum) (plural, **phyla**) In Linnaean classification, the taxonomic category above class.

الشعبة (الجمع شعب) في التصنيف الحيوي، الفئة التصنيفية فوق الفئة.

physiology (fi′-zē-ol′-uh-ji) The study of the functions of an organism's structures

الفيزيولوجيا دراسة وظائف بناء الكائنات الحية.

pineal gland (pin′-ē-ul) An outgrowth of the vertebrate brain that secretes the hormone melatonin, which coordinates daily and seasonal body activities such as the sleep/wake circadian rhythm with environmental light conditions.

الغدة الصنوبرية نمو الدماغ الفقاري الذي يفرز هرمون الميلاتونين، والذي ينظم أنشطة الجسم اليومية والموسمية مثل النوم/الاستيقاظ والنظم اليوماوي مع ظروف الضوء البيئي.

pinocytosis (pē′-nō-sī-tō′-sis) Cellular "drinking"; a type of endocytosis in which the cell takes fluid and dissolved solutes into small membranous vesicles.

الاحتساء "شرب" خلوي؛ نوع من الالتقام الذي تقوم فيه الخلية بأخذ المشروبات والمواد الذائبة المنحلة إلى حويصلات غشائية.

pistil Part of the reproductive organ of an angiosperm, a single carpel or a group of fused carpels.

المدقة جزء من العضو الإنجابي للكائن الحي، خباء فردي أو مجموعة من الخباءات الملتحمة.

pith Part of the ground tissue system of a dicot plant. Pith fills the center of a stem and may store food.

لباب جزء من نظام النسيج الأرضي للنبات ثنائي الفلقة. يملأ اللباب قلب الجذع وربما يخزن الطعام.

placenta (pluh-sen′-tuh) In most mammals, the organ that provides nutrients and oxygen to the embryo and helps dispose of its metabolic wastes; formed of the embryo's chorion and the mother's endometrial blood vessels.

المشيمة في معظم الثدييات، العضو الذي يوفر المواد الغذائية والأوكسجين للجنين ويساعد على التخلص من الفضلات الأيضية؛ المتكونة من مشيماء الجنين والأوعية الدموية لبطانة الرحم الخاصة بالأم.

plasma cell An antibody-secreting B cell.

خلية البلازما خلية B مفرزة للأجسام المضادة.

plasma membrane The membrane at the boundary of every cell that acts as a selective barrier to the passage of ions and molecules into and out of the cell; consists of a phospholipid bilayer with embedded proteins.

غشاء البلازما الغشاء الموجود على حدود كل خلية والذي يعمل كحاجز انتقائي لمرور الأيونات والجزيئات داخل وخارج الخلية؛ يتكون من طبقة مزدوجة من الشحم الفسفوري إضافة إلى البروتينات.

plasmodesma (plaz′-mō-dez′-muh) (plural, **plasmodesmata**) An open channel in a plant cell wall through which strands of cytoplasm connect from adjacent cells.

رابطة هيولية (الجمع رابطات هيولية) قناة مفتوحة في جدار خلية النبات والتي من خلالها تتصل طاقات السيتوبلازم من الخلايا المجاورة.

plasmodium A single mass of cytoplasm containing many nuclei.

متصورة كتلة مفردة من السيتوبلازم تحتوي على نوي عديدة.

polar covalent bond A covalent bond between atoms that differ in electronegativity. The shared electrons are pulled closer to the more electronegative atom, making it slightly negative and the other atom slightly positive.

الرابط القطبي التساهمي رابط تساهمي بين الذرات التي تختلف في الكهربية السلبية. يتم سحب الإلكترونات المشتركة بالقرب من الذرات ذات الكهربية السلبية الأعلى، مما يجعلها سلبية بينما تكون الذرة الأخرى إيجابية.

polar molecule A molecule containing polar covalent bonds and having an unequal distribution of charges.

الجزيء القطبي جزيء يحتوي على روابط تساهمية قطبية ويحتوي على توزيع غير متساو للشحنات.

polymer (pol′-uh-mer) A large molecule consisting of many identical or similar monomers linked together by covalent bonds.

البولمر جزيء كبير يحتوي على العديد من المونمورات المتطابقة أوالمتشابهة مرتبطة مع بعضها بعضًا عن طريق روابط تساهمية.

polynucleotide (pol′-ē-nū′-klē-ō-tīd) A polymer made up of many nucleotide monomers covalently bonded together.

عديد النوكليوتيد بولمر مصنوع من العديد من مونومرات النوكليوتيد مرتبطة مع بعضها البعض تساهميا.

polypeptide A polymer (chain) of amino acids linked by peptide bonds.

عديد الببتيد بولمر (سلسلة) من الأحماض الأمينية مرتبطة بروابط الببتيد.

polysaccharide (pol′-ē-sak′-uh-rīd) A carbohydrate polymer of many monosaccharides (sugars) linked by dehydration reactions.

السكاريد المتعددة بولمر كربوهيدرات للعديد من أحاديات السكاريد (السكر) مرتبطة من خلال تفاعلات الجفاف.

positive feedback A type of control in which a change triggers mechanisms that amplify that change.

الارتجاع الإيجابي نوع من التحكم يدشن فيه التغيير الآليات التي تعظم من هذا التغيير.

posterior Pertaining to the rear, or tail, of a bilaterally symmetric animal.

خلفي مرتبط بمؤخرة أو ذيل حيوان متماثل ثنائيا.

potential energy The energy that matter possesses because of its location or arrangement. Water behind a dam possesses potential energy, and so do chemical bonds.

الطاقة الجهدية الطاقة التي تتميز بها المادة بسبب موقعها أو ترتيبها. الطاقة خلف السد تتمتع بطاقة جهدية وكذلك الروابط الكيميائية.

prepuce (prē′-pyūs) A fold of skin covering the head of the clitoris or penis.

القلفة طية من الجلد تغطي رأس البظر أو العضو الذكري.

primary consumer In the trophic structure of an ecosystem, an organism that eats plants or algae.

المستهلك الأولي في البناء الاغتذائي للمباءة، كائن حي يعيش على النباتات أو الطحالب.

primary oocyte (ō′-uh-sīt) A diploid cell, in prophase I of meiosis, that can be hormonally triggered to develop into an egg.

الخلية البيضية الأولية خلية صبغية، في الطور الأول I من الانتصاف، التي يمكن أن تبدأ هرمونيا لتطوير البيضة.

primary spermatocyte (sper-mat′-eh-sīt′) A diploid cell in the testis that undergoes meiosis I.

الخلية النطفية الأولية خلية صبغية في الخصية تقوم بعملية الانتصاف I.

primary structure The first level of protein structure; the specific sequence of amino acids making up a polypeptide chain.

البناء الأولي المستوى الأول من بناء البروتين؛ التسلسل المحدد للأحماض الأمينية المصنوعة في سلسلة عديد الببتيد.

producer An organism that makes organic food molecules from CO_2, H_2O, and other inorganic raw materials: a plant, alga, or autotrophic prokaryote.

المنتج كائن حي يقوم بعمل جزيئات الطعام العضوي من ثاني أكسيد الكربون والماء، والمواد غير العضوية الأخرى: النبات والطحالب وبدائيات النواة ذاتية التغذي.

product An ending material in a chemical reaction

المنتج مادة نهائية في التفاعل الكيميائي.

progestin (prō-jes′-tin) One of a family of steroid hormones, including progesterone, produced by the mammalian ovary. Progestins prepare the uterus for pregnancy.

البروجستين واحد من أسرة الهرمونات الستيرويدية، بما في ذلك البروجستيرون، الذي يتم إنتاجه عن طريق المبيض الثديي. البروجستينات تعمل على إعداد الرحم للحمل.

prokaryotic cell (prō-kār′-ē-ot′-ik) A type of cell lacking a membrane-enclosed nucleus and other membrane-enclosed organelles; found only in the domains Bacteria and Archaea.

خلية بدائية النواة نوع من الخلايا ينقصه نوي مغلف بالأغشية وغيرها من العضيات المغلفة بالأغشية؛ الموجودة فقط في ممالك البكتيريا والبدائيات.

prometaphase The second stage of mitosis, during which the nuclear envelope fragments and the spindle microtubules attach to the kinetochores of the sister chromatids.

طليعة الطور التالي في الانقسام الخلوي المرحلة الثانية من التفتل، والذي ينقسم فيها غلاف النواة للحيز الحركي للكروماتيدات الشقيقة.

promoter A specific nucleotide sequence in DNA located near the start of a gene that is the binding site for RNA polymerase and the place where transcription begins.

المعزاز تسلسل نوكليوتيد محدد في الدنا يقع بالقرب من بداية الجين والذي يعد الموقع الرابط لبوليميراز الدنا والمكان الذي يبدأ فيه الانتساخ.

prophase The first stage of mitosis, during which the chromatin condenses to form structures (sister chromatids) visible with a light microscope and the mitotic spindle begins to form, but the nucleus is still intact.

الطور الأول في الانقسام الخلوي المرحلة الأولى في التفتل، والذي يتكثف خلالها الكروماتين لتكوين بناءات (الكروماتيدات الشقيقة) مرئية بالمجهر الضوئي ويبدأ الأنيبيب المغزلي في التكون، ولكن لا تزال النواة فيها سالمة.

prostate gland (pros′-tāt) A gland in human males that secretes a thin fluid that nourishes the sperm.

غدة البروستاتا غدة في الذكور من الجنس البشري والتي تفرز سائلًا رقيقًا يغذي الحيوانات المنوية.

protein A functional biological molecule consisting of one or more polypeptides folded into a specific three-dimensional structure.

البروتين جزيء حيوي وظيفي يتكون من واحد أو أكثر من عديد الببتيد مطوية في بناء محدد ثلاثي الأبعاد.

proton A subatomic particle with a single positive electrical charge, found in the nucleus of an atom.

البروتون جسيم من دوين الذرة به شحنة كهربائية موجبة مفردة، موجود في نواة الذرة.

pulmonary artery A large blood vessel that conveys blood from the heart to a lung.

الشريان الرئوي وعاء دموي كبير ينقل الدم من القلب إلى الرئة.

pulmonary circuit The branch of the circulatory system that supplies the lungs. *See also* systemic circuit.

الدورة الرئوية فرع من الجهاز الدوري والذي يعمل على تزويد الرئة. انظر أيضا الدورة النظامية.

pulmonary vein A blood vessel that conveys blood from a lung to the heart.

الأوردة الرئوية أوعية دموية تنقل الدم من الرئة إلى القلب.

Punnett square A diagram used in the study of inheritance to show the results of random fertilization.

مربع بانيت مخطط يستخدم في دراسة الوراثة لعرض نتائج التخصيب العشوائي.

Q

quaternary consumer (kwot′-er-ner-ē) An organism that eats tertiary consumers.

المستهلك الرابع كائن حي يعيش على المستهلك الثالثي.

quaternary structure The fourth level of protein structure; the shape resulting from the association of two or more polypeptide subunits.

البناء الرابع المستوى الرابع من بناء البروتين؛ الشكل الذي ينتج عن ربط واحد أو أكثر من الوحدات الفرعية لعديد الببتيد.

R

radioactive isotope An isotope whose nucleus decays spontaneously, giving off particles and energy.

النظير المشع نظير تتحلل النواة الخاصة به بصورة تلقائية، مما يوفر جسيمات وطاقة.

radiolarian A protist that moves and feeds by means of threadlike pseudopodia and has a mineralized support structure composed of silica.

أولاني يتحرك ويتغذى عن طريق أقدام كاذبة تشبه الخيوط وبه بناء دعم معدني مؤلف من السيليكا.

radula (rad′-yū-luh) A toothed, rasping organ used to scrape up or shred food; found in many molluscs.

المقلحة عضو ذو أسنان يستخدم لكشط وتقطيع الطعام؛ موجود في الرخويات.

reabsorption In the vertebrate kidney, the reclaiming of water and valuable solutes from the filtrate.

إعادة الامتصاص في كلية الفقاريات، استعادة الماء والمحاليل ذات القيمة من الرشاحة.

reactant A starting material in a chemical reaction.

المتفاعل مادة بادئة في التفاعل الكيميائي.

recessive allele An allele that has no noticeable effect on the phenotype of a gene when the individual is heterozygous for that gene.

أليل متنح أليل ليه له تأثير ملحوظ على النمط الظاهري للجين عندما يكون الفرد متخالف مع هذا الجين.

Recommended Dietary Allowance (RDA) A recommendation for daily nutrient intake established by a national scientific panel.

النظام الغذائي الموصى به (RDA) توصية بالمواد الغذائية اليومية التي تقرها لوحة علمية دولية.

rectum The terminal portion of the large intestine where the feces are stored until they are eliminated.

المستقيم الجزء الطرفي من الأمعاء الدقيقة حيث يخزن فيها البراز حتى يتم التخلص منه.

GLOSSARY

redox reaction Short for **reduction-oxidation** reaction; a chemical reaction in which electrons are lost from one substance (oxidation) and added to another (reduction).

تفاعل الأكسدة والاختزال تفاعل قصير من الاختزال والأكسدة؛ تفاعل كيميائي يتم فيه فقد الإلكترونات من مادة واحدة (الأكسدة) وإضافتها إلى مادة أخرى (الاختزال).

reduction The gain of electrons by a substance involved in a redox reaction; always accompanies oxidation.

الاختزال الحصول على الإلكترونات عن طريق المادة التي تدخل في تفاعلات الأكسدة؛ دائما ما تصاحب الأكسدة.

regeneration The regrowth of body parts from pieces of an organism.

التجدد إعادة نمو أجزاء الجسم من قطع من الكائن الحي.

releasing hormone A kind of hormone secreted by the hypothalamus that promotes the release of hormones from the anterior pituitary.

الهرمونات المطلقة نوع من الهرمونات التي تفرز عن طريق الوطاء والتي تساعد على إطلاق الهرمونات من النخامية الأمامية.

reproduction The creation of new individuals from existing ones.

الإنجاب إنشاء أفراد جدد من أفراد موجودة.

reproductive system The organ system responsible for reproduction.

نظام الإنجاب النظام العضوي المسؤول عن الإنجاب.

reptile Member of the clade of amniotes that includes snakes, lizards, turtles, crocodilians, and birds, along with a number of extinct groups, such as dinosaurs.

الزاحف عضو من متعدد الأفرع من الحيوانات السلوية التي تشتمل على الثعابين والسحالي والسلاحف والتماسيح والطيور مع عدد من المجموعات النادرة كالديناصورات.

respiratory system The organ system that functions in exchanging gases with the environment. It supplies the blood with O_2 and disposes of CO_2.

الجهاز التنفسي النظام العضوي الذي يعمل في تبادل الغازات مع البيئة. يمد الدم بالأكسجين ويتخلص من ثاني أكسيد الكربون.

ribonucleic acid (RNA) (rī-bō-nū-klā′-ik) A type of nucleic acid consisting of nucleotide monomers with a ribose sugar and the nitrogenous bases adenine (A), cytosine (C), guanine (G), and uracil (U); usually single-stranded; functions in protein synthesis, gene regulation, and as the genome of some viruses.

الحمض النووي الريبي (الرنا) نوع من الحمض النووي الذي يتكون من مونومر النكليوتيد مع سكر الريبوز وأدينين القاعدة النيتروجينية (A) وسيتوزين (C) والغوانين (G) واليوراثيل (U)؛ في جديلة واحدة؛ يعمل في تمثيل البروتين، وتنظيم الجينات وكجينوم لبعض الفيروسات.

ribosome (rī′-buh-sōm) A cell structure consisting of RNA and protein organized into two subunits and functioning as the site of protein synthesis in the cytoplasm. In eukaryotic cells, the ribosomal subunits are constructed in the nucleolus.

الريبوسوم بناء خلية يتكون من الرنا وبروتين منظم في وحدتين فرعيتين ويعمل كمكان لتمثيل البروتين في السيتوبلازم. في الخلايا الحيوانية، يتم إنشاء الوحدات الفرعية الريبوسومية في النواة.

ribozyme (rī′-bō-zīm) An RNA molecule that functions as an enzyme.

الرايبوزيم جزيء رنا يعمل كإنزيم.

RNA polymerase (puh-lim′-uh-rās) A large molecular complex that links together the growing chain of RNA nucleotides during transcription, using a DNA strand as a template.

بوليميراز الرنا مركب جزيئي كبير يربط السلسلة التي تنمو من نكليوتيدات الرنا أثناء الانتساخ، باستخدام طيقان الدنا كقالب.

root hair An outgrowth of an epidermal cell on a root, which increases the root's absorptive surface area.

شعر الجذر انتبات لخلايا بشروية في الجذر، والذي يزيد منطقة السطح الممتص في الجذر.

root system All of a plant's roots, which anchor it in the soil, absorb and transport minerals and water, and store food.

النظام الجذري جميع جذور النباتات، التي تتواجد في التربة، يمتص وينقل المعادن والماء ويخزن الطعام.

rough endoplasmic reticulum (reh-tik′-yuh-lum) That portion of the endoplasmic reticulum with ribosomes attached that make membrane proteins and secretory proteins.

الشبكة الهيولية الباطنة الخشنة هذا الجزء من الشبكة الهيولية الباطنة المرتبط بها الريبوسوم الذي يكون بروتينات الغشاء والبروتينات الإفرازية.

ruminant (rū′-min-ent) An animal, such as a cow or sheep, with multiple stomach compartments housing microorganisms that can digest cellulose.

مجتر حيوان، مثل الأبقار أو الغنم، مع كائنات حية صغيرة للغاية متعددة في المعدة والتي تهضم السلولوز.

S

salt A compound resulting from the formation of ionic bonds; also called an ionic compound.

الملح مركب ينتج من تكون الروابط الأيونية؛ يسمى أيضا المركب الأيوني.

saturated fatty acid A fatty acid in which all carbons in the hydrocarbon tail are connected by single bonds and the maximum number of hydrogen atoms are attached to the carbon skeleton. Saturated fats and fatty acids solidify at room temperature.

الأحماض الدهنية المشبعة حمض دهني تتصل فيه جميع الكربونات في الذيل الهيدروكربوني من خلال روابط مفردة والحد الأقصى من ذرات الهيدروجين مرتبطة بهيكل الكربون. تتجمد الدهون المشبعة الأحماض الدهنية في درجة حرارة الغرفة.

scavenger An animal that feeds on the carcasses of dead animals.

الكاسح حيوان يتغذى على جثث الحيوانات الميتة.

sclereid (sklār′-ē-id) In plants, a very hard sclerenchyma cell found in nutshells and seed coats.

السكلريد في النباتات، خلايا النسيج الداعم الموجودة في قشر البندق وأغلفة البذرة.

sclerenchyma cell (skluh-ren′-kē-muh) In plants, a supportive cell with rigid secondary walls hardened with lignin.

خلايا النسيج الداعم في النباتات، خلية داعمة بها جدران ثانوية صلبة مدعومة باللغنين.

scrotum A pouch of skin outside the abdomen that houses a testis and functions in cooling sperm, keeping them viable.

الصفن مجموعة من الجلد خارج البطن والتي تحوي الخصية وتعمل على تبريد الحيوان المنوي وتجعله قابلًا للحياة.

second law of thermodynamics The principle stating that every energy conversion reduces the order of the universe, increasing its entropy. Ordered forms of energy are at least partly converted to heat.

القانون الثاني من الديناميكية الحرارية المبدأ الذي يفيد بأن كل تحول في الطاقة يميل إلى نهاية عظمى في الكون، مما يزيد اعتلاجه. أشكال مرتبة من الطاقة تتحول إلى حرارة بصورة جزئية.

secondary consumer An organism that eats primary consumers.

المستهلك الثانوي كائن حي يتغذى على المستهلك الرئيسي.

secondary oocyte (ō′-uh-sīt′) A haploid cell resulting from meiosis I in oogenesis, which will become an egg after meiosis II.

الخلية البيضية الثانوية خلية فردانية تنتج من الانتصاف I في تكون البيضة، والتي ستصبح بيضة بعد الانتصاف II.

secondary spermatocyte (sper-mat′-uh-sīt′) A haploid cell that results from meiosis I in spermatogenesis and becomes a sperm cell after meiosis II.

الخلية النطفية الثانوية خلية فردانية تنتج من الانتصاف I في الإنطاف وتصبح خلية حيوان منوي بعد الانتصاف II.

secondary structure The second level of protein structure; the regular local patterns of coils or folds of a polypeptide chain.

البناء الثانوي المستوى الثاني من بناء البروتين؛ النماذج المحلية المنتظمة من الطيات أو الملفات لسلسلة متعددة الببتيد.

secretion The discharge of molecules synthesized by a cell.

الإفراز التخلص من الجزيئات التي تقوم الخلايا بتمثيلها.

seed A plant embryo packaged with a food supply within a protective covering.

البذرة جنين النبات المعبأ بإمداد الطعام داخل غطاء واقي.

selective permeability (per′-mē-uh-bil′-uh-tē) A property of biological membranes that allows some substances to cross more easily than others and blocks the passage of other substances altogether.

النفوذية الانتقائية خاصية من الأغشية الحيوية التي تسمح لبعض المواد بالعبور بسهولة أكثر من غيرها من المواد وتعوق مرور مواد أخرى تماما.

self-fertilize A form of reproduction that involves fusion of sperm and egg produced by the same individual organism.

التخصيب الذاتي نوع من الإنجاب يشتمل على اندماج حيوان منوي وبيضة أنتجها نفس الكائن الحي.

semen (sē′-mun) The sperm-containing fluid that is ejaculated by the male during orgasm.

المني السائل الذي يحتوي على الحيوانات المنوية والذي يقذفه الذكر عند الوصول إلى النشوة الجنسية.

semiconservative model Type of DNA replication in which the replicated double helix consists of one old strand, derived from the old molecule, and one newly made strand.

نموذج التنسخ المحافظ جزئيًا نوع من تنسخ الحمض النووي الريبي منقوص الأكسجين (DNA) تتكون فيه اللولبة المزدوجة المستنسخة من طاق قديم، مستمد من جزيء قديم، وطاق جديد.

seminiferous tubule (sem′-uh-nif′-uh-rus) A coiled spermproducing tube in a testis.

النبيبات الناقلة للمني أنبوب منتج للحيوانات المنوية.

sensory receptor A specialized cell or neuron that detects stimuli and sends information to the central nervous system.

المستقبلات الحسية خلية أو عصبون متخصص يكتشف المنبهات ويرسلها إلى النظام العصبي المركزي.

sepal (sē′-pul) A modified leaf of a flowering plant. A whorl of sepals encloses and protects the flower bud before it opens.

الكاسية ورقة معدلة من النبات المزهر. دوارة من الكاسية تحيط ببرعم الزهرة وتحميه قبل التفتح.

sexual reproduction The creation of genetically unique offspring by the fusion of two haploid sex cells (gametes), forming a diploid zygote.

التوالد الجنسي إنشاء سلالة فريدة وراثيا من خلال دمج خليتين جنسيتين فردانيتين (أعراس)، مكونة زيجوت ضعفاني.

shoot system All of a plant's stems, leaves, and reproductive structures.

نظام البراعم جميع سوق وأوراق النبات وكذلك البناء الإنجابية الخاصة بها.

sieve plate An end wall in a sieve-tube element that facilitates the flow of phloem sap.

الصفيحة المنخلية جدار نهائي في عنصر الأنبوب المنخلي يسهل تدفق العصارة اللحائية.

sieve-tube element A food-conducting cell in a plant; also called a sieve-tube member. Chains of sieve-tube elements make up phloem tissue.

عنصر الأنبوب المنخلي خلية صانعة للطعام في النبات؛ تسمى أيضا عضو الأنبوب المنخلي. سلاسل من عناصر الأنبوب المنخلي تكون النسيج اللحائي.

signal In behavioral ecology, a stimulus transmitted by one animal to another animal.

الإشارة في الإيكولوجيا السلوكية، منبه ينتقل من حيوان إلى آخر.

silencer A eukaryotic DNA sequence that functions to inhibit the start of gene transcription; may act analogously to an enhancer by binding a repressor. *See also* enhancer.

المهدئ تسلسل دنا حيواني يعمل على منع بدء استنساخ الجين؛ ربما يعمل بالقياس كمعزاز من خلال ربط القامع. انظر أيضا المعزاز.

single circulation A circulatory system with a single pump and circuit, in which blood passes from the sites of gas exchange to the rest of the body before returning to the heart.

الدورة الفردية نظام دوري بضخة ودورة واحدة، يمر فيه الدم من مواقع تبادل الغازات إلى بقية الجسم قبل الرجوع إلى القلب.

sister chromatid (krō′-muh-tid) One of the two identical parts of a duplicated chromosome in a eukaryotic cell. Prior to mitosis, sister chromatids remain attached to each another at the centromere.

شقا الصبغي المتآخيان واحد من اثنين من الأجزاء المتماثلة لكروموسوم متكرر في الخلية الحيوانية. قبل التفتل، شقا الصبغي المتآخيان تظل متصلة ببعضها بعضا في القسيم المركزي.

skeletal muscle A type of striated muscle attached to the skeleton; generally responsible for voluntary movements of the body.

العضلة الهيكلية نوع من العضلات المحززة المتصلة بالهيكل؛ تكون مسؤولة بشكل عام عن الحركة الإرادية للجسم.

skeletal system The organ system that provides body support and protects body organs, such as the brain, heart, and lungs.

النظام الهيكلي النظام العضوي الذي يدعم الجسم ويحمي أعضاء الجسم، مثل المخ والقلب والرئتين.

small intestine The longest section of the alimentary canal. It is the principal site of the enzymatic hydrolysis of food macromolecules and the absorption of nutrients.

الأمعاء الدقيقة أطول قسم من القناة الغذائية. الموقع الرئيسي للحملأة الإنزيمية للجزيئات الكبروية للطعام وامتصاص المواد الغذائية.

smooth endoplasmic reticulum That portion of the endoplasmic reticulum that lacks ribosomes.

الشبكة الهيولية الباطنة الملساء هذا الجزء من الشبكة الهيولية الباطنة الذي ينقصه الريبوسوم.

smooth muscle A type of muscle lacking striations; responsible for involuntary body activities.

العضلة الملساء نوع من العضلات ينقصه التخطيط؛ مسؤول عن أنشطة الجسم اللاإرادية.

SNP *See* single nucleotide polymorphism (SNP).

SNP تعدد الأشكال الفردية للنكليوتيد (SNP).

solute (sol′-yūt) A substance that is dissolved in a solution.

المذاب مادة تنحل في محلول.

solution A liquid that is a homogeneous mixture of two or more substances.

المحلول سائل عبارة عن خليط متجانس من مادتين أو أكثر.

solvent The dissolving agent of a solution. Water is the most versatile solvent known.

المذيب عنصر إذابة للمحلول. الماء هو المذيب المعروف الأكثر تنوعا.

species A group whose members possess similar anatomical characteristics and have the ability to interbreed and produce viable, fertile offspring.

النوع مجموعة تمتلك أعضاؤها صفات تشريحية ولديها القدرة على التزاوج وإنتاج سلالة قابلة للحياة مخصبة.

sperm A male gamete.

الحيوان المنوي عرس ذكوري.

spermatogenesis (sper-mat′-ō-jen′-uh-sis) The formation of sperm cells.

الإنطاف تكون خلايا الحيوان المنوي.

sphincter (sfink′-ter) A ringlike band of muscle fibers that regulates passage between some compartments of the alimentary canal.

المصرة رابط تشبه الحلقة من الألياف العضلية التي تنظم المرور بين بعض الحجيرات في القناة الغذائية.

spinal cord A jellylike bundle of nerve fibers that runs lengthwise inside the spine in vertebrates and integrates simple responses to certain stimuli.
الحبل الشوكي حزمة تشبه الهلام من الألياف العصبية التي تعمل طوليا داخل العمود الفقري في الفقاريات وتنطوي على استجابات بسيطة لمنبهات معينة.

spore (1) In plants and algae, a haploid cell that can develop into a multicellular individual without fusing with another cell. (2) In prokaryotes, protists, and fungi, any of a variety of thick-walled life cycle stages capable of surviving unfavorable environmental conditions.
البوغ (1) في النباتات والطحالب، خلية فردانية تستطيع التطور في فرد متعدد الخلايا دون الاندماج مع خلية أخرى. (2) في بدائيات النواة والأولانيات والفطريات، أي تشكيلة من مراحل دورة الحياة ذات الجدران السميكة القادرة على العيش في ظروف بيئية غير مستحبة.

sporophyte (spōr′-uh-fīt) The multicellular diploid form in the life cycle of organisms undergoing alternation of generations; results from a union of gametes and meiotically produces haploid spores that grow into the gametophyte generation.
النابت البوغي شكل صبغي متعدد الخلايا في دورة حياة الكائنات الحية التي تخضع لتبدل الأجيال؛ تنتج عن اتحاد الأعراس وتنتج أبواغ فردانية تنمو في جيل النابتة العرسية.

stamen (stā′-men) A pollen-producing male reproductive part of a flower, consisting of a filament and an anther.
العضو المذكر في الأزهار الجزء الإنجابي الذكري المنتج للطلع في الزهرة، والذي يتكون من خيط ومئبر.

starch A storage polysaccharide in plants; a polymer of glucose.
النشا متعدد السكاريد للتخزين في النباتات؛ بولمر الجلوكوز.

start codon (kō′-don) On mRNA, the specific three-nucleotide sequence (AUG) to which an initiator tRNA molecule binds, starting translation of genetic information.
رامزة البدء في mRNA، تسلسل ثلاثي النكليوتيد المحدد (AUG) والذي يرتبط به منشئ جزيء tRNA، والذي يبدأ في ترجمة المعلومات الوراثية.

stem The part of a plant's shoot system that supports the leaves and reproductive structures.
الجذع جزء من نظام البراعم في النبات والذي يدعم الأوراق والبناءات الإنجابية.

stem cell An unspecialized cell that can divide to produce an identical daughter cell and a more specialized daughter cell, which undergoes differentiation.
الخلية الجذعية خلية غير محددة تستطيع الانقسام لإنتاج خلية وليدة متماثلة وخلايا وليدة متخصصة، والتي تخضع للتمييز.

steroid (ster′-oyd) A type of lipid whose carbon skeleton is in the form of four fused rings with various chemical groups attached. Examples are cholesterol, testosterone, and estrogen
الستيرويد نوع من الشحم يكون هيكل الكربون الخاص به في صورة أربع حلقات مدمجة مع العديد من المجموعات الكيميائية. أمثلة على ذلك الكوليسترول والتستوستيرون والإستروجين.

steroid hormone A lipid made from cholesterol that acts as a regulatory chemical, entering a target cell and activating the transcription of specific genes.
الهرمون الستيرويدي شحم مصنوع من الكوليسترول والذي يعمل كمادة كيميائية منظمة، تدخل إلى الخلايا المستهدفة وتعمل على تنشيط استنساخ جينات معينة.

stigma (stig′-muh) (plural, **stigmata**) The sticky tip of a flower's carpel, which traps pollen grains.
السمة (الجمع **سمات**) الطرف اللصوق من خباء الزهرة، والذي يجذب حبات اللقاح.

stimulus (plural, **stimuli**) (1) In the context of a nervous system, any factor that causes a nerve signal to be generated. (2) In behavioral biology, an environmental cue that triggers a specific response.
المنبه (الجمع **منبهات**) (1) في سياق النظام العصبي، أي عنصر يسبب تولد إشارة عصبية. (2) في الأيكولوجيا السلوكية، إلماع بيئي يبعث على استجابة معينة.

stoma (stō′-muh) (plural, **stomata**) A pore surrounded by guard cells in the epidermis of a leaf. When stomata are open, CO_2 enters a leaf, and water and O_2 exit. A plant conserves water when its stomata are closed.
الفغرة (الجمع **فغرات**) مسام محاط بخلايا حارسة في ظهارة الأوراق. عندما تكون الفوهة مفتوحة، يدخل ثاني أكسيد الكربون إلى الورقة ويخرج الماء والأكسجين. نبات يحفظ الماء عندما تكون الفوهات مغلقة.

stomach An organ in a digestive tract that stores food and performs preliminary steps of digestion.
المعدة عضو في السبيل الهضمي يخزن الطعام ويقوم بإجراء مراحل بدائية من الهضم.

stop codon In mRNA, one of three triplets (UAG, UAA, UGA) that signal gene translation to stop.
رامزة التوقف في mRNA، أحد ثلاث ثلاثيات (UAG، UAA، UGA) التي تبعث رسالة إلى الجين للتوقف.

stroma (strō′-muh) The dense fluid within the chloroplast that surrounds the thylakoid membrane and is involved in the synthesis of organic molecules from carbon dioxide and water. Sugars are made in the stroma by the enzymes of the Calvin cycle.
السدي سائل مكثف في صانعة الكلوروفيل الذي يحيط بغشاء التيلاكويدات ويدخل في تمثيل الجزيئات العضوية من ثاني أكسيد الكربون والماء. يتم صنع السكر في السدي عن طريق إنزيمات دورة كالفين.

substrate A surface in or on which an organism lives.
الركيزة سطح يعيش عليه الكائن الحي.

substrate feeder An organism that lives in or on its food source, eating its way through the food.
آكل الركيزة كائن حي يعيش في أو على مصدر الطعام الخاص به، حيث يأكل ما يحفره في طريقه.

sugar-phosphate backbone In a polynucleotide (DNA or RNA strand), the alternating chain of sugar and phosphate to which nitrogenous bases are attached.
عمود فقري من السكر والفوسفات في عديد النكليوتيد (طيقان الرنا والدنا)، السلسلة البديلة للسكر والفوسفات التي ترتبط بها قواعد النيتروجين.

superior vena cava (vē′-nuh kā′-vuh) A large vein that returns oxygen-poor blood to the heart from the upper body and head. See also inferior vena cava.
الوريد الأجوف العلوي وريد كبير يعيد الدم غير الغني بالأوكسجين إلى القلب من الجزء العلوي من الجسم والرأس. انظر أيضا الوريد الأجوف السفلي.

surface tension A measure of how difficult it is to stretch or break the surface of a liquid. Water has a high surface tension because of the hydrogen bonding of surface molecules.
التوتر السطحي مقياس لمدى صعوبة مد أو كسر سطح السائل. يتميز الماء بتوتر سطحي عالي بسبب الترابط الهيدروجيني لجزيئات السطح.

surfactant A substance secreted by alveoli that decreases surface tension in the fluid that coats the alveoli.
فاعل بالسطح مادة تفرز عن طريق أسناخ تقلل من التوتر السطحي في السائل الذي يغلف الأسناخ.

symbiosis (sim′-bē-ō-sis) A physically close association between organisms of two or more species.
التعايش ارتباط وثيق فيزيائيا بين كائنات حية من نوعين أو أكثر.

synapse (sin′-aps) A junction between two neurons, or between a neuron and an effector cell. Electrical or chemical signals are relayed from one cell to another at a synapse.
المشبك ربط بين عصبونين أو بين عصبون وخلية مستفعلة. إشارات إلكترونية أو كيميائية من خلية إلى خلية أخرى في المشبك.

systemic circuit The branch of the circulatory system that supplies oxygen-rich blood to, and carries oxygen-poor blood away from, organs and tissues in the body. *See also* pulmonary circuit.
الدورة النظامية فرع من النظام الدوري يوفر الدم الغني بالأوكسجين ويحمل الدم غير الغني بالأوكسجين بعيدا عن الأعضاء والأنسجة في الجسم. انظر أيضا الدورة الرئوية.

systems biology An approach to studying biology that aims to model the dynamic behavior of whole biological systems based on a study of the interactions among the system's parts.
بيولوجيا الأنظمة منهج لدراسة البيولوجيا التي تهدف إلى قولبة السلوك الديناميكي للأنظمة البيولوجية كلية استنادا إلى دراسة التفاعلات التي تتم بين أجزاء النظام.

systole (sis′-tō-lē) The contraction stage of the heart cycle, when the heart chambers actively pump blood. *See also* diastole.
الانقباض مرحلة انقباض دورة القلب، عندما تضخ غرف القلب الدم بفعالية. انظر أيضا الانبساط.

T

T cell A type of lymphocyte that matures in the thymus and is responsible for the cell-mediated immune response. T cells are also involved in humoral immunity.
خلية T نوع من اللمفاوية الذي ينضج في التوتة ويكون مسؤولا عن استجابة مناعة الخلية المتوسطة. خلايا T تدخل أيضا في المناعة الخلطية.

target cell A cell that responds to a regulatory signal, such as a hormone.
الخلية المستهدفة خلية تستجيب إلى الإشارات النظامية، مثل الهرمون.

taxis (tak′-sis) (plural, **taxes**) Virtually automatic orientation toward or away from a stimulus.
الانجذاب (الجمع **انجذابات**) توجه تلقائي نحو المنبه أو بعيدًا عنه.

taxon A named taxonomic unit at any given level of classification.
الأصنوفة وحدة تصنيفية محددة في أي مستوى من التصنيف.

taxonomy The scientific discipline concerned with naming and classifying the diverse forms of life
التصنيف المبدأ العلمي الذي يهتم بتسمية وتصنيف الأشكال المتعددة للحياة.

technology The application of scientific knowledge for a specific purpose, often involving industry or commerce but also including uses in basic research.
التكنولوجيا تطبيق المعرفة العلمية لمجموعة معينة، غالبا تشتمل على الصناعة أو التجارة ولكنها تشمل أيضا الأبحاث الأساسية.

telomere (tel′-uh-mēr) The repetitive DNA at each end of a eukaryotic chromosome.
القسيم الطرفي دنا متكررة في كل نهاية كرموسوم حيواني.

telophase The fifth and final stage of mitosis, during which daughter nuclei form at the two poles of a cell. Telophase usually occurs together with cytokinesis.
الطور الانتهائي في الانقسام الخلوي المرحلة الخامسة والأخيرة في التفتل، والتي تتكون خلالها النوى الوليدة في قطبي الخلية. يحدث الطور الانتهائي عادة مع الحرائك الخلوية.

temperature A measure of the intensity of heat in degrees, reflecting the average kinetic energy or speed of molecules.
درجة الحرارة مقياس لشدة الحرارة بالدرجات، والذي يعكس متوسط الطاقة الحركية أو سرعة الجزيئات.

tendril A modified leaf used by some plants to climb around a fixed structure.
المحلاقية ورقة معدلة تستخدمها بعض النباتات للتسلق حول بناء ثابت.

terminal bud Embryonic tissue at the tip of a shoot, made up of developing leaves and a compact series of nodes and internodes.
البرعم الطرفي نسيج جنيني في طرف البرعم، مصنوع من الأوراق النامية ومجموعة من العقد والعقد البينية.

terminator A special sequence of nucleotides in DNA that marks the end of a gene. It signals RNA polymerase to release the newly made RNA molecule and then to depart from the gene.
المنهي تسلسل خاص للنوكليوتيدات في الدنا والتي تحدد نهاية الجين. تبعث بإشارات إلى بوليميراز الرنا لانبعاث جزيء الدنا المصنوع حديثا كي يرحل من الجين.

tertiary consumer (ter′-shē-ār-ē) An organism that eats secondary consumers.
المستهلك الثالث كائن حي يتغذى على المستهلك الثاني.

tertiary structure The third level of protein structure; the overall three-dimensional shape of a polypeptide due to interactions of the R groups of the amino acids making up the chain.
البناء الثالث المستوى الثالث من بناء البروتينات؛ الشكل الكلي ثلاثي الأبعاد لعديد الببتيد بسبب تفاعلات مجموعات R من الأحماض الأمينية والتي تشكل السلسلة.

testicle A testis and scrotum together.
الخُصيّة خصية وصفن معا.

testis (plural, **testes**) The male gonad in an animal. The testis produces sperm and, in many species, reproductive hormones.
الخصية (الجمع **خصى**) الغدة التناسلية الذكرية في الحيوانات. تنتج الخصية الحيوان المنوي، في العديد من الأنواع تنتج الهرمونات الإنجابية.

testosterone (tes-tos′-tuh-rōn) An androgen hormone that stimulates an embryo to develop into a male and promotes male body features.
التستوستيرون هرمون أندروجن والتي تنبه الجنين كي يتطور ليصبح ذكرًا ويعمل على زيادة خصائص جسم الذكر.

tetrad A paired set of homologous chromosomes, each composed of two sister chromatids. Tetrads form during prophase I of meiosis, when crossing over may occur.
الرباعية زوج الكروموسومات المتجانسة، كل منها مؤلف من اثنين من الكروماتيدات الشقيقة. تتشكل الرباعيات أثناء الطور الأول I من الانتصاف، عندما يحدث تصالب.

thalamus (thal′-uh-mus) An integrating and relay center of the vertebrate forebrain; sorts and relays selected information to specific areas in the cerebral cortex.
المهاد مركز تكاملي وتتابعي للدماغ الأمامي للفقاريات؛ يرتب ويرحل معلومات منتقاه لأماكن معينة في قشرة المخ.

theory A widely accepted explanatory idea that is broader in scope than a hypothesis, generates new hypotheses, and is supported by a large body of evidence.
النظرية فكرة تفسيرية مقبولة بصورة واسعة والتي تعد أوسع من الفرضية، تولد فرضيات جديدة، وتدعمها أدلة قوية.

thermodynamics The study of energy transformation that occurs in a collection of matter. *See* first law of thermodynamics; second law of thermodynamics.
الديناميكية الحرارية دراسة استحالة الطاقة التي تتم في تجميع المواد. انظر القانون الأول للديناميكية الحرارية؛ القانون الثاني للديناميكية الحرارية.

thermoregulation The homeostatic maintenance of internal temperature within a range that allows cells to function efficiently.
تنظيم الحرارة الصيانة الاستتبابية لدرجة الحرارة الداخلية في نطاق يسمح للخلية بالعمل بصورة فعالة.

three-domain system A system of taxonomic classification based on three basic groups: Bacteria, Archaea, and Eukarya.
النظام ثلاثي الممالك نظام مصنف يستند إلى ثلاث مجموعات أساسية: البدائيات والبكتيريا وحقيقية النواة.

threshold The minimum change in a membrane's voltage that must occur to generate an action potential (nerve signal).
العتبة الحد الأدنى من التغيير في جهدية الغشاء الذي يجب أن يحدث ليولد جهد العمل (إشارة العصب).

thylakoid (thī′-luh-koyd) A flattened membranous sac inside a chloroplast. Thylakoid membranes contain chlorophyll and the molecular complexes of the light reactions of photosynthesis. A stack of thylakoids is called a granum.
التيلاكويدات كيس غشائي مسطح داخل صانعة الكلوروفيل. تحتوي أغشية التيلاكويدات على مركبات الكلوروفيل ذات التفاعلات الخفيفة في التمثيل الضوئي. المدس من التيلاكويدات يسمى قمح.

thymine (T) (thī′-min) A single-ring nitrogenous base found in DNA.
الثيمين (T) قاعدة نيتروجينية أحادية الحلقات موجودة في الدنا.

GLOSSARY

Ti plasmid A bacterial plasmid that induces tumors in plant cells that the bacterium infects. Ti plasmids are often used as vectors to introduce new genes into plant cells. Ti stands for "tumor inducing."
بلازميدة Ti بلازميدة بكتيرية تشتمل على أورام في خلايا النبات والتي تصيبها البكتيريا. تستخدم بلازميدة Ti غالبا كناقلات لتقديم جينات جديدة في خلايا النبات. تشير Ti إلى "حاملة للورم".

tissue An integrated group of cells with a common function, structure, or both.
النسيج مجموعة متكاملة من الخلايا لها وظيفة أو بناء شائع أو كليهما معا.

tissue system One or more tissues organized into a functional unit within a plant or animal.
النظام النسيجي نسيج أو أكثر منظم في وحدة وظيفية في النبات أو الحيوان.

tonicity The ability of a solution surrounding a cell to cause that cell to gain or lose water.
التوترية قدرة المحلول على إحاطة الخلية ليجعل الخلية تكتسب أو تفقد الماء.

topsoil The uppermost soil layer, consisting of a mixture of particles derived from rock, living organisms, and humus.
التربة العليا الجزء العلوي من طبقة التربة، والذي يتكون من خليط من الجسيمات المشتقة من الصخور، والكائنات الحية والدبال.

trace element An element that is essential for life but required in extremely minute amounts.
العنصر الزهيد عنصر ضروري للحياة ولكنه مطلوب في بكميات قليلة للغاية.

trachea (trā′-kē-uh) (plural, **tracheae**) The windpipe; the portion of the respiratory tube that passes from the larynx to the two bronchi.
الرغامي (الجمع **رغاميات**) جزء من أنبوب التنفس التي تمر من الحنجرة إلى الشعبتين الهوائيتين.

tracheal system A system of branched, air-filled tubes in insects that extends throughout the body and carries oxygen directly to cells.
النظام الرغامي نظام من الأنابيب المتفرعة المليئة بالهواء في الحشرات التي تمر خلال الجسم وتحمل الأوكسجين مباشرة إلى الخلايا.

tracheid (trā′-kē-id) A tapered, porous, water-conducting and supportive cell in plants. Chains of tracheids or vessel elements make up the water-conducting, supportive tubes in xylem.
القصيبية خلية مدببة مسامية حاملة للماء وداعمة في النباتات. تشكل سلاسل القصيبيات أو عناصر الأوعية الأنابيب الحاملة للماء والداعمة في نسيج الخشب.

trait A variant of a character found within a population, such as purple or white flowers in pea plants.
الصفة متغير من الصفات موجودة في العينة، مثل الزهور الأرجوانية أو البيضاء في نبات البازيلا.

trans fat An unsaturated fat, formed artificially during hydrogenation of vegetable oils, which is linked to health risks.
الدهون التقابلية دهون غير مشبعة، تتكون صناعيا أثناء هدرجة الزيوت النباتية، والتي ترتبط بالمخاطر الصحية.

transcription The synthesis of RNA on a DNA template.
الاستنساخ تخليق نماذج الرنا والدنا.

transduction (1) The transfer of bacterial genes from one bacterial cell to another by a phage. (2) *See* sensory transduction. (3) *See* signal transduction pathway.
التحاس (1) تحول الجينات البكتيرية من خلية بكتيرية إلى خلية أخرى عن طريق الفج. (2) انظر التحاس الحسي. (3) انظر ممرات تحاس الإشارة.

transformation The incorporation of new genes into a cell from DNA that the cell takes up from the surrounding environment.
الاستحالة دمج جينات جديدة في خلية من الدنا والتي تلتقطها الخلية من البيئة المحيطة.

translation The synthesis of a polypeptide using the genetic information encoded in an mRNA molecule. There is a change of "language" from nucleotides to amino acids.
الترجمة تخليق عديد الببتيد باستخدام معلومات وراثية مشفرة في جزيء mRNA. هناك تغير في "اللغة" من النوكليوتيدات إلى الأحماض الأمينية.

translocation (1) During protein synthesis, the movement of a tRNA molecule carrying a growing polypeptide chain from the A site to the P site on a ribosome. (The mRNA travels with it.)
الإزفاء أثناء تخليق البروتينيات، حركة جزيء tRNA التي تحمل سلسلة عديد الببتيد النامية من موقع A إلى موقع P في الريبوسوم. (mRNA تتحرك معها).

transpiration The evaporative loss of water from a plant.
النتح الفقدان البخاري للماء من النبات.

transpiration-cohesion-tension mechanism A transport mechanism that drives the upward movement of water in plants. Transpiration exerts a pull that is relayed downward along a string of molecules held together by cohesion and helped upward by adhesion.
آلية النتح-التماسك-التوتر آلية نقل تشغل حركة الماء لأعلى في النباتات. يبذل النتح سحبة إلى أسفل تنقسم إلى مراحل مع سلسلة جزيئات مجمعة مع بعضها البعض عن طريق التماسك ومرفوعة لأعلى عن طريق مسك مكوناتها.

transport vesicle A small membranous sac in a eukaryotic cell's cytoplasm carrying molecules produced by the cell. The vesicle buds from the endoplasmic reticulum or Golgi and eventually fuses with another organelle or the plasma membrane, releasing its contents.
حويصلة النقل كيس غشائي صغير في سيتوبلازم الخلية الحيوانية يحمل الجزيئات التي تنتجها الخلية. تتبرعم الحويصلة من الشبكة الهيولية الباطنة أو الغولجي ثم تندمج مع عضيات أخرى أو غشاء بلازمي، والذي يبعث.

true-breeding Referring to organisms for which sexual reproduction produces offspring with inherited traits identical to those of the parents. The organisms are homozygous for the characteristics under consideration.
استيلاد حقيقي تشير إلى الكائنات التي ينتج التوالد الجنسي فيها سلالة بصفات موروثة متماثلة مع تلك الخاصة بالأب. وتكون الكائنات الحية زيجوت متماثلة الألائل للصفات.

tuber An enlargement at the end of a rhizome in which food is stored.
الحدبة توسيع في نهاية الجذمور الذي يتم تخزين الطعام فيه.

tumor An abnormal mass of rapidly growing cells that forms within otherwise normal tissue.
الورم كتلة غير عادية ذات خلايا سريعة النمو تتكون خلال أنسجة عادية أخرى.

U

unsaturated fatty acid A fatty acid that has one or more double bonds between carbons in the hydrocarbon tail and thus lacks the maximum number of hydrogen atoms. Unsaturated fats and fatty acids do not solidify at room temperature.
الأحماض الدهنية غير المشبعة أحماض دهنية بها رابط مزدوج أو أكثر بين الكربونات في ذيل الهيدروجين ومن ثم ينقصها الحد الأقصى من عدد ذرات الهيدروجين. الدهون غير المشبعة والأحماض الدهنية لا تتجمد في درجة حرارة الغرفة.

uracil (U) (yū′-ruh-sil) A single-ring nitrogenous base found in RNA.
يوراسيل (U) قاعدة نيتروجينية أحادية الحلقات موجودة في الرنا.

urea (yū-rē′-ah) A soluble form of nitrogenous waste excreted by mammals and most adult amphibians.
يوريا شكل ذواب من الفضلات النيتروجينية التي تخرجها الثدييات وجميع البرمائيات البالغة.

ureter (yū-rē′-ter or yū′-reh-ter) A duct that conveys urine from the kidney to the urinary bladder.
الحالب قناة تنقل البول من الكلية إلى المثانة.

urethra (yū-rē′-thruh) A duct that conveys urine from the urinary bladder to the outside. In the male, the urethra also conveys semen out of the body during ejaculation.
الإحليل قناة تنقل البول من المثانة إلى الخارج. في الذكور، الإحليل ينقل المني خارج الجسم أثناء عملية القذف.

uric acid (yū′-rik) An insoluble precipitate of nitrogenous waste excreted by land snails, insects, birds, and some reptiles.

حمض البوليك مترسب ذواب من الفضلات النيتروجينية التي تخرج عن طريق قوقع الأرض والحشرات والطيور وبعد الزواحف.

urinary bladder The pouch where urine is stored prior to elimination.

المثانة الجيبة التي يتجمع فيها البول قبل التخلص منه.

urinary system The organ system that forms and excretes urine while regulating the amount of water and ions in the body fluids.

الجهاز البولي النظام العضوي الذي يشكل ويخرج البول عند تنظيم كمية الماء والأيونات في سوائل الجسم.

urine Concentrated filtrate produced by the kidneys and excreted by the bladder.

البول رشاحة مركزة تنتج عن طريق الكلى وتخرج عن طريق المثانة.

uterus (yū′-ter-us) In the reproductive system of a mammalian female, the organ where the development of young occurs; the womb.

الرحم في الجهاز الإنجابي لدى الأنثى في الثدييات، العضو الذي يتم فيه نمو الصغار؛ الرحم.

V

vacuole (vak′-ū-ōl) A membrane-enclosed sac that is part of the endomembrane system of a eukaryotic cell and has diverse functions.

الفجوة كيس مغلف بالغشاء والذي يعد جزءًا من جهاز الغشاء الداخلي للخلية الحيوانية وله وظائف عديدة.

vagina (vuh-jī′-nuh) Part of the female reproductive system between the uterus and the outside opening; the birth canal in mammals; also accommodates the male's penis and receives sperm during copulation.

المهبل جزء من الجهاز الإنجابي للأنثى بين الرحم والفتحة الخارجية؛ قناة الولادة في الثدييات؛ يأوي العضو الذكري للذكور ويستقبل الحيوانات المنوية أثناء الجماع.

vas deferens (vas def′-er-enz) (plural, **vasa deferentia**) Part of the male reproductive system that conveys sperm away from the testis; the sperm duct; in humans, the tube that conveys sperm between the epididymis and the common duct that leads to the urethra.

الأسهر(القناة الناقلة للمني) جزء من الجهاز الإنجابي لدى الذكور والذي ينقل الحيوانات المنوية من الخصية؛ قناة الحيوانات المنوية؛ في البشر، الأنبوب الذي ينقل الحيوانات المنوية بين البربخ والقناة الشائعة التي تؤدي إلى الإحليل.

vascular bundle (vas′-kyū-ler) A strand of vascular tissues (both xylem and phloem) in a plant stem.

الحزمة الوعائية مجموعة من الأنسجة الوعائية (نسيج الخشب واللحاء) في جذع النبات.

vascular cylinder The central cylinder of vascular tissue in a plant root.

الأسطوانة الوعائية الأسطوانة المركزية من الأنسجة الوعائية في جذر النبات.

vascular tissue system A transport system formed by xylem and phloem throughout the plant. Xylem transports water and minerals, while phloem transports sugars and other organic nutrients.

النظام النسيجي الوعائي نظام نقل يتكون من نسيج الخشب واللحاء في النبات. ينقل نسيج الخشب الماء والمعادن، بينما ينقل اللحاء السكر وغيرها من المواد الغذائية العضوية.

vector In molecular biology, a piece of DNA, usually a plasmid or a viral genome, that is used to move genes from one cell to another.

الناقل في البيولوجيا الجزيئية، قطعة من الدنا، بلازميد أو جينوم فيروس، والذي يستخدم في نقل الجينات من خلية إلى أخرى.

vein (1) In animals, a vessel that returns blood to the heart. (2) In plants, a vascular bundle in a leaf, composed of xylem and phloem.

الوريد (1) في الحيوانات، وعاء يعيد الدم إلى القلب. (2) في النباتات، مجموعة وعائية في الأوراق تتألف من اللحاء ونسيج الخشب.

ventilation A mechanism that provides for the flow of air or water over a respiratory surface.

التهوية آلية تعمل على تدفق الهواء أو الماء على السطح التنفسي.

ventral Pertaining to the underside, or bottom, of a bilaterally symmetric animal.

بطني متعلق بالجانب السفلي أو قاع الحيوان المتماثل ثنائيا.

ventricle (ven′-truh-kul) (1) A heart chamber that pumps blood out of the heart. (2) A space in the vertebrate brain filled with cerebrospinal fluid.

البطين (1) غرفة في القلب تضخ الدم خارج القلب. (2) مساحة في المخ الفقاري مليئة بالسائل النخاعي.

venule (ven′-yūl) A vessel that conveys blood between a capillary bed and a vein.

الوريد وعاء ينقل الدم بين سرير الشعيرات والوريد.

vertebra (ver′-tuh-bruh) (plural, **vertebrae**) One of a series of segmented skeletal units that enclose the nerve cord, making up the backbone of a vertebrate animal.

الفقرة (الجمع فقرات) واحد من مجموعة من الوحدات الهيكلية التي تغلف الحبل العصبي، مما يشكل العمود الفقري للحيوانات الفقارية.

vertebral column Backbone, composed of a series of segmented units called vertebrae.

العمود الفقاري العمود الفقري، المؤلف من سلسلة من الوحدات المقسمة التي تسمى فقرات.

vesicle (ves′-i-kul) A sac made of membrane in the cytoplasm of a eukaryotic cell.

الحويصلة كيس مصنوع من الغشاء في سيتوبلازم الخلية الحيوانية.

vessel element A short, open-ended, water-conducting and supportive cell in plants. Chains of vessel elements or tracheids make up the water-conducting, supportive tubes in xylem.

عنصر الوعاء خلية قصيرة ذات نهاية مفتوحة حاملة للماء داعمة في النباتات. سلاسل من عناصر الوعاء أو القصيبات المصنوعة من الأنابيب الحاملة للماء والداعمة في نسيج الخشب.

villus (vil′-us) (plural, **villi**) A finger-like projection of the chorion of the mammalian placenta. Large numbers of villi increase the surface areas of these organs.

الزغابة (الجمع زغابات) إسقاط يشبه الإصبع للمشيماء في مشيمة الثدييات. أعداد كبيرة من الزغابات تزيد منطقة السطح لهذه الأعضاء.

virus A microscopic particle capable of infecting cells of living organisms and inserting its genetic material. Viruses are generally not considered to be alive because they do not display all of the characteristics associated with life.

الفيروس جسيم مجهري يستطيع إصابة الخلايا الخاصة بالكائنات الحية ووضع المادة الجينية الخاصة به. لا تعتبر الفيروسات حية لأنه لا يظهر عليها جميع الخصائص المرتبطة بالحياة.

visceral mass (vis′-uh-rul) One of the three main parts of a mollusc, containing most of the internal organs.

الكتلة الحشوية واحدة من ثلاثة أجزاء من الرخوي الذي يحتوي على جميع الأعضاء الداخلية.

vital capacity The maximum volume of air that a mammal can inhale and exhale with each breath.

القدرة الحيوية الحد الأقصى من كمية الهواء الذي تستطيع الثدييات تنفسها وإخراجها في كل عملية تنفس.

vitamin An organic nutrient that an organism requires in very small quantities. Many vitamins serve as coenzymes or parts of coenzymes.

الفيتامين مادة غذائية عضوية يحتاجها الكائن الحي بكميات صغيرة للغاية. العديد من الفيتامينات تعمل كإنزيمات مساعدة أو جزء من الإنزيمات المساعدة.

GLOSSARY

vocal cord One of a pair of bands of elastic tissue in the larynx. Air rushing past the tensed vocal cords makes them vibrate, producing sounds.

الحبل الصوتي واحد من زوج من النطاقات ذات الأنسجة المرنة في الحنجرة. الهواء الذي يمر على الأحبال الصوتية المشدودة فيجعلها تهتز محدثة الصوت.

vulva The collective term for the external female genitalia.

فرج المرأة المصطلح الجامع للأعضاء التناسلية الخارجية للأنثى.

W

wavelength The distance between crests of adjacent waves, such as those of the electromagnetic spectrum.

طول الموجة المسافة بين قمم الموجات المجاورة، مثل تلك الخاصة بالمجال الكهرومغناطيسي.

wood Secondary xylem of a plant. *See also* heartwood; sapwood.

الخشب نسيج الخشب الثانوي في النبات. انظر أيضا قلب الشجرة وخشب الساج.

X

xylem (zī′-lum) The nonliving portion of a plant's vascular system that provides support and conveys xylem sap from the roots to the rest of the plant. Xylem is made up of vessel elements and/or tracheids, water-conducting cells. Primary xylem is derived from the procambium. Secondary xylem is derived from the vascular cambium in plants exhibiting secondary growth.

نسيج الخشب الجزء غير الحي من الجهاز الوعائي للنبات والذي يدعم وينقل خشب الساج من الجذور إلى بقية النبات. نسيج الخشب مصنوع من عناصر أوعية و/أو قصيبات، وخلايا حاملة للماء. نسيج الخشب الأولي مشتق من النسيج الجنيني الأولي. نسيج الخشب الثانوي مشتق من الكامبيوم الوعائي في النباتات والذي يؤدي إلى النمو الثانوي.

Y

yeast A single-celled fungus that inhabits liquid or moist habitats and reproduces asexually by simple cell division or by the pinching of small buds off a parent cell.

الخميرة فطريات أحادية الخلايا تعوق السوائل أو الموئلات الرطبة من الإنجاب اللاجنسي عن طريق انقسام خلايا بسيط أو عن طريق براعم صغيرة من الخلية الرئيسية.

Z

zygote (zī′-gōt) The diploid fertilized egg, which results from the union of a sperm cell nucleus and an egg cell nucleus.

العرس بيضة ضعفانية مخصبة، تنتج من اتحاد نواة خلية حيوان منوي ونواة خلية بيضة.

Index

U

V

X

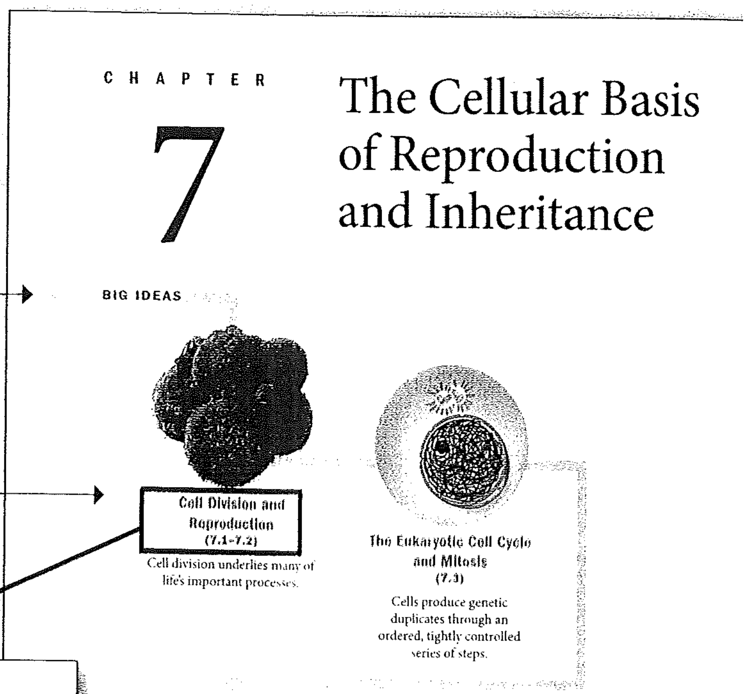
Z

To the Student: How to use this book

Introduce yourself to the chapter.

See where you are headed. Look for the ***Big Ideas,*** which open each chapter and provide a transit map to a set of overarching concepts.

Remember the big picture. Look for the ***main headings*** that organize the chapter around the big ideas.



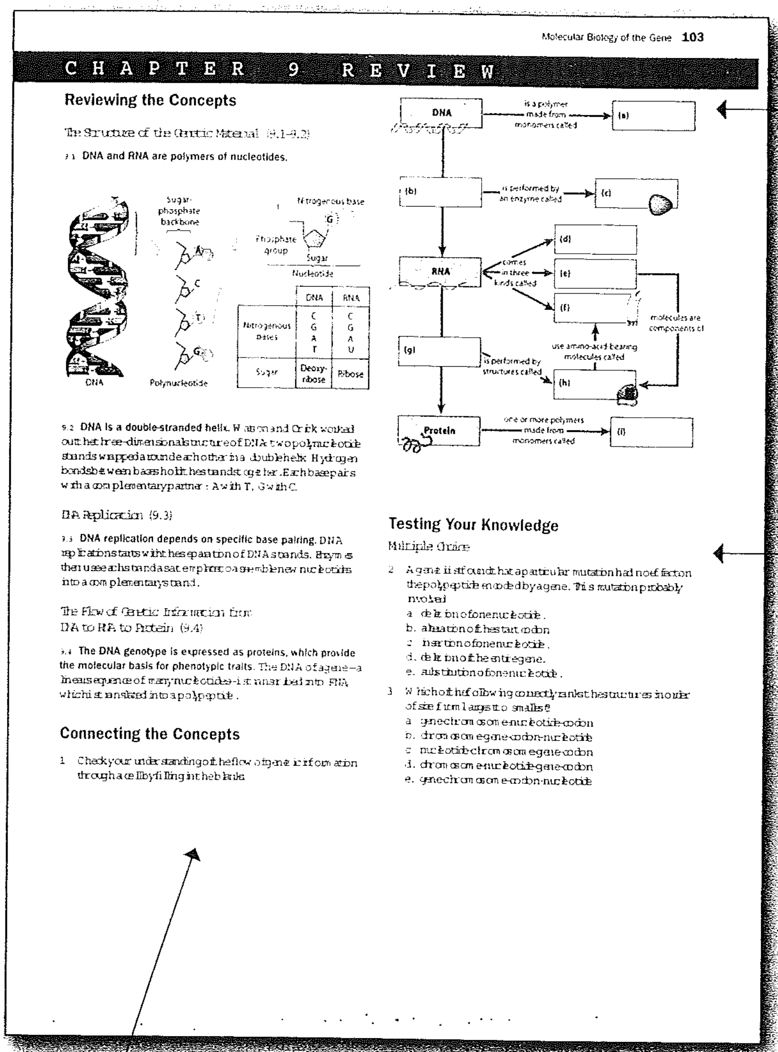
Understand biology one concept at a time. Each module features a ***central concept,*** announced in its heading.

Focus on what's important.

Use both text and figures as you study. The ***figures*** illuminate the text and vice versa. Text and figures are always together—so you'll never have to turn a page to find what you need.

To the Student: How to use this book *(continued)*

Feel confident going into the test.


Molecular Biology of the Gene 103

CHAPTER 9 REVIEW

Reviewing the Concepts

9.1 DNA and RNA are polymers of nucleotides.

9.2 DNA is a double-stranded helix.

9.3 DNA replication depends on specific base pairing.

9.4 The DNA genotype is expressed as proteins, which provide the molecular basis for phenotypic traits.

Connecting the Concepts

Testing Your Knowledge

Connect the chapter's key concepts.
Connecting the Concepts activities test your ability to link topics from different modules and include concept mapping, labeling, and categorizing exercises.

Prepare for the test.
Use the questions that appear in the ***Testing Your Knowledge*** section to prepare for your upcoming tests.

Review the main points.
The ***Reviewing the Concepts*** section provides helpful summary diagrams and references back to the text.